



Cornell  
University

ANNOUNCEMENTS

Graduate School  
*Physical Sciences*

1969-70

#### CORNELL UNIVERSITY ANNOUNCEMENTS

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I certify that the statements made by me above are correct and complete.

Kelvin J. Arden, *Editor*

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# ADMINISTRATION

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Paul J. Leurgans, B.A., M.S., Ph.D., Associate Dean of the Graduate School  
Frank W. Young, B.A., M.A., Ph.D., Secretary of the Graduate Faculty

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Professor Joseph A. Carreiro (Member-at-Large), term expires 1971  
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Professor Donald F. Holcomb (Member-at-Large), term expires 1971  
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## GRADUATE SCHOOL OF MEDICAL SCIENCES

1300 York Avenue  
New York, New York 10021

John E. Deitrick, M.D., Dean of the Graduate School of Medical Sciences

Julian R. Rachele, B.A., M.A., Ph.D., Assistant Dean of the Graduate School of Medical Sciences

## UNIVERSITY PROFESSORS-AT-LARGE

Professors-at-Large are distinguished nonresident members of the University Faculty. During short visits to the campus, of up to a month's duration, made at irregular intervals, they hold seminars, give public lectures, and consult informally with students and faculty.

Pierre Aigrain  
Raymond Aron  
Sir Eric Ashby  
Elliott Carter  
Daniel Cosío Villegas  
Manfred Eigen  
Gino Gorla

Mark Kac  
L. S. B. Leakey  
Barbara McClintock  
Sir Peter Medawar  
Charles S. Singleton  
Georg Henrik von Wright  
Elizabeth Mary Wilkinson

The business office of the Graduate School and the office of the Dean are in Sage Graduate Center. Office hours are 8:30 A.M. to 4:30 P.M., Monday through Friday. The office is closed on Saturday.

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# Cornell University

## GRADUATE EDUCATION AT CORNELL

Graduate education at Cornell is based on the principle that no objective of a university lies deeper in its tradition or springs higher in its aspiration than does the nurture of scholarship. The advancement of learning, the methods of learning, and the criticism of learning occupy the highest reaches of university life and work. Graduate education brings into fruitful contact the most distinguished scholars and the most advanced students, that learning may be shared and that wisdom may be at least glimpsed.

The Graduate School provides an environment within which scholarly capability is encouraged to emerge, thrive, and transmit itself. The School arranges a set of conditions congenial to the student who is prepared to profit from the availability of advanced courses of study; the opportunity for sustained reflection; the companionship of active, full-time fellow students; the most highly developed libraries, laboratories, and other facilities for research; the prospect of independent discovery or recovery, of evaluation or revaluation; the daily presence of distinguished teachers; and the hope of attaining a firmly based structure of knowledge and a free and independent habit of judgment.

Freedom and independence are key qualities of scholarship, and graduate studies at Cornell are ordered so as to preserve them for both teacher and student. The Cornell principle is that scholars are begotten by other scholars, that judgments are formed by associating with the best judges, that learning lives in the unbroken succession of the learners and the learned, that genuine scholarship is always humane and rests ultimately on personal teaching and personal learning, that success in graduate studies must consist of satisfying the professor rather than a mute schedule of requirements. Graduate School standards are high, but they are maintained there not by the pronouncements of an office but rather by the men after whom such standards are themselves fashioned.

The Cornell graduate student selects not only the study he wishes to pursue, but also the scholar under whose tutelage he wishes to pursue it. The candidate himself, no one else, makes the choice. Some candidates when they apply for admission have in mind the man or men with

whom they wish to study. Those who do not are granted, under a temporary adviser, a semester in which to form an acquaintance and to come to a decision. The supervising professor is called the student's chairman. The chairman and his associate or associates, also chosen by the student, form the student's Special Committee. All such matters as the outlines of study, the observation of progress, the setting of general examinations, the conduct of the thesis, and other exercises leading to a graduate degree are determined within this small circle—the student and the professors he has selected to direct him. So successful is this arrangement and so strongly does Cornell believe in it, that the Special Committee enjoys extraordinary freedom and independence in conducting the student to his degree. The Graduate School sets no course requirement, no credit-hours requirement, no grade requirement. Within the broad agreements of the Graduate Faculty concerning residence, oral examinations, and thesis, the student will be recommended for his degree whenever his Special Committee judges him ready to receive it. When the Committee is satisfied, the requirements are.

The Cornell Graduate School has an enrollment of 3,300 students, and the Graduate Faculty consists of about 1,100 members. In contrast to many other graduate schools, approximately 98 percent of the students are full-time degree candidates, with the majority in programs leading to the Ph.D. degree.

*The University expects that all graduate students at Cornell University shall, at all times, act with a mature and morally responsible attitude, recognizing the basic rules of society and the common rights of others.*

## ADMISSION

### APPLICATIONS

To be considered for admission to the Graduate School an applicant must (1) hold a baccalaureate degree granted by a faculty or university of recognized standing or have completed studies equivalent to those required for a baccalaureate degree at Cornell, (2) have adequate preparation for graduate study in his chosen field of instruction, (3) have fluent command of the English language, and (4) present evidence of promise in advanced study and research. Students from United States colleges and universities should be in the top third of their graduating class.

Applications for admission should be requested from the Graduate School, Sage Graduate Center, Cornell University, Ithaca, N.Y. 14850. Two letters of recommendation should be sent from the applicant's major instructors. Official transcripts from all the institutions of higher learning attended, and, where required, the Graduate Record Examination or the Miller Analogies Test scores complete the application.



All applications from residents or citizens of the United States or Canada must be accompanied by a \$15.00 nonrefundable fee. Applicants from other countries who have been accepted for admission must pay this fee before registration.

Fellowship and admission applicants are urged to take the Graduate Record Examination (GRE) Aptitude (Verbal and Quantitative) Tests of the Educational Testing Service, and to have the scores sent to the Cornell Graduate School as part of their application materials. Information about the times and places of test administrations may be obtained directly from the Educational Testing Service, Princeton, New Jersey 08540. The Field listings, pages 53 ff., should be consulted for Fields requiring the scores of both the Aptitude Test and the pertinent Advanced Test.

Foreign applicants whose native language is not English and who have received their secondary or advanced education in the English language should submit to the Graduate School a statement to this effect signed by a responsible officer of a United States Embassy or Consulate or by an appropriate official of the educational institution involved. If English has not been the medium of instruction, applicants must take the Test of English as a Foreign Language by arrangement with Educational Testing Service, Princeton, New Jersey 08540. This testing program is available throughout the world. Information on times and places for administration of the test may be obtained directly from the address given above. The test score must be reported directly by the testing organization to the Graduate School as part of the essential application information. Since this test is diagnostic, no final action on applications will be taken until the scores have been received. Admission to those applicants whose scores indicate unsatisfactory command of English may be denied, or it may be made contingent upon evidence of improvement.

## CATEGORIES OF ADMISSION

### Degree Programs

It is expected that most applicants for admission intend to pursue a program for an advanced degree. Applicants may specify candidacy for the Master of Arts or Master of Science or one of the professional Master's degrees listed on pages 26-30. However, since Cornell has a strong commitment to doctoral work, most students are encouraged to enroll in a doctoral program. In some fields, students registered in a doctoral program may be required to seek a Master's degree as an initial step in the program.

Only under unusual circumstances will anyone who already holds an advanced degree be permitted to apply for the same degree.

## Provisional Candidacy

Under circumstances in which it is difficult to evaluate the academic background of qualified applicants, they may be admitted to *provisional* candidacy. Ordinarily only one semester of study in provisional candidacy is permitted, and the student who fails to qualify for candidacy at the end of that time may be requested to withdraw from the University.

## Noncandidacy

When staff and facilities are available, the Graduate School will admit some applicants who do not intend to work toward an advanced degree at Cornell but who have special objectives for formal study or scholarly work at the graduate level, provided they satisfy all the entrance requirements expected of degree candidates. Registration in noncandidacy is restricted to two semesters.

## CHANGE OF STATUS

A student who wishes to change his status from nondegree candidacy to regular candidacy or from one degree or Field to another, or who, after receiving the Master's degree, wishes to undertake candidacy for the doctorate, must submit a request in writing to the Dean of the Graduate School asking for transfer to the new status. Reasons for the change in status should be given. Provisional candidacy is automatically reviewed at the end of each semester; therefore, no letter is necessary.

## DEGREE REQUIREMENTS

### THE SPECIAL COMMITTEE

The general degree requirements of the Graduate School are kept at a minimum in order to give the student maximum flexibility in choosing a desirable program of studies. Since progress in graduate study depends so much on the individual student's situation, there are no course or grade requirements imposed by the Graduate School. The student's program is developed with the aid and direction of a Special Committee chosen by the student from the area of studies of interest and is designed to best fit the specific needs and desires of the individual student. Satisfactory progress toward the degree is judged solely by the Special Committee rather than by any arbitrary standards imposed by the Graduate School.

The Special Committee under which a Master of Arts or a Master of

Science candidate carries on his work is composed of a chairman who represents the major subject, and one representative of an appropriate minor subject. The Special Committee of a doctoral student is composed of a chairman, representing the major subject, and two other members representing other areas of interest. The chairman of the Special Committee directs the student's thesis research. Some Fields of study require two minor subjects for doctoral programs while others require only one, but all Ph.D. Special Committees have three members.

The selection of the Field and the major subject, as well as the chairman of the Special Committee, is made by the incoming student. It is the privilege of the graduate student to ask any member of the Graduate School Faculty who is in the Field of his major subject to serve as his chairman. The chairman in turn advises the student about minor subjects and faculty members who might be appropriate to represent them on his Special Committee. The choice of major and minor subjects and the formation of the Special Committee must be recorded in the Graduate School Office within two weeks of the beginning of the first term of residency. However, since the student may be uncertain of his aspirations at that time, he is encouraged to change the membership of his Special Committee as his aims become more definite.

In some of the larger Fields of the Graduate School the difficulty in making a wise selection of a Committee is so great that the Field Representative or other faculty member may serve temporarily as the chairman of the Special Committee while the student seeks a permanent chairman and committee to supervise his programs of study.

The members of the Special Committee decide upon the student's program of study and research and whether he is making satisfactory progress toward the degree. They conduct and report on oral examinations, and they approve the thesis. The Committee and the student constitute an independent working unit. All members of the Graduate School Faculty, however, are free to participate in the scheduled examinations and review the theses of candidates for degrees.

The organization of the Graduate School at Cornell is based on a concept of fields of study which is independent of colleges and departments. It is thus possible for a graduate student to take courses in any division of the University and to choose major and minor subjects without regard to organizational lines.

## RESIDENCE

The Graduate Faculty regards study in residence as essential. Although a person working off-campus may attain proficiency in a technique or even in a field of knowledge, he may fail in other ways to attain the breadth of knowledge necessary for scholarly work. In addition to contact with the libraries and physical facilities of the University, he needs the daily acquaintance, company, aid, and stimulus of others engaged in similar pursuits. He should form the habit of attending lectures, seminars, and meetings of groups in whose activities he takes interest.

Full-time study for one semester with satisfactory accomplishment

## 10 DEGREE REQUIREMENTS

constitutes one residence unit. The Graduate School Faculty requires that each candidate for a Master's degree earn two units of residence, and for the Ph.D. degree six units of residence. However, the time required to obtain the degree generally exceeds those minimum requirements.

A student must complete all the requirements for the Master's degree in four years and for a doctoral degree in seven years.

A student in a doctoral program may earn no more than two units for work done in Summer Research, Summer Session, and the Division of Extramural Courses. At least four of the six required units must be earned as a full-time student, earning three-quarters of a residence unit or more each term, and two of the last four units must be earned in successive terms of full-time study on the Cornell campus.

### Transfer of Residence

Candidates for the Master's degree may not count study in other graduate schools as part of their residence. Candidates for the doctorate may be permitted to count study for the Master's degree as equivalent to two residence units; those who have received training of an exceptional quality and amount may petition for more. No commitment regarding this may be made until after the student has entered into residence and his Special Committee has had further opportunity to judge his accomplishments. The residence transferred must not exceed that which would have been earned under similar circumstances at Cornell. Credits secured during study as an undergraduate or as a special student, even for work in courses designed primarily or wholly for graduate students, will not be allowed.

### Summer Session

To receive residence credit through registration in the Summer Session, the candidate must register in both the Summer Session and the Graduate School and must file a statement of courses satisfactory to his Special Committee. The completion of eight or more hours of credit in the eight-week session, or a minimum of six hours in the six-week session, will count as one-half or two-fifths of a residence unit respectively, if approved in advance and reported as acceptable by the candidate's Special Committee.

Requirements for Master's degrees may, upon approval of the appropriate graduate Field, be completed solely during the summer period if instruction in the chosen major and minor subjects is offered. Only two residence units for study in the Summer Session may be accepted in fulfillment of requirements for the doctorate. Upon recommendation by the Special Committee of a student and on approval by the Dean of the Graduate School, residence may be transferred for study done in one preceding Cornell Summer Session period if such study is attested to be an integral part of the graduate program subsequently undertaken.

## SUMMER RESEARCH

To encourage students to continue their studies during the summer period, no tuition or fees are charged for summer research if the student has been registered during the previous academic year. Substantial funds are also available for summer fellowship and research assistantship support. A special summer fellowship program is also available for those students who have held teaching fellowship appointments during the previous academic year. Students have access to the regular services of the University Clinic and Hospital during the summer without charge.

Under certain conditions, students may also accumulate residence credit in the summer term.

## Part-Time Studies

Essentially, all graduate students at Cornell are full-time students. In those cases where employment is necessary, students may hold positions requiring up to ten hours of work without reduction of residence credit. Teaching fellows and research assistants whose duties require up to twenty hours a week are able to obtain full residence credit.

The legislation with respect to eligibility of part-time employees for residence units is as follows.

EMPLOYMENT	RESIDENCE UNITS ALLOWABLE PER SEMESTER		
	<i>Contributory in the major field of study and on campus</i>	<i>Noncontributory but on campus</i>	<i>Off campus</i>
<i>Total clock hrs. per week</i>			
0-10 hours	1 unit	1 unit	1 unit
11-20 hours	1 unit	$\frac{3}{4}$ unit	$\frac{3}{4}$ unit
21-30 hours	$\frac{3}{4}$ unit	$\frac{1}{2}$ unit	(See paragraph below)

If the employment is more than twenty clock-hours per week and is off campus, or if it is more than thirty clock-hours per week under any circumstances, a maximum of two-fifths of a residence unit per semester may be earned through registration in the Division of Extramural Courses, but this will be permitted only on the basis of petition approved prior to the time that the work is undertaken. For the degree of Master of Arts or Master of Science a maximum of one unit, and for the degree of Ph.D. a maximum of two units of residence may be earned in this way.

Therefore, under the circumstances described above, degree candidates may accumulate residence units for course work completed through the Division of Extramural Courses. Instruction is offered in certain fields

## 12 DEGREE REQUIREMENTS

of study both on and off the campus. Fifteen credit hours are the equivalent of one residence unit, and six credit hours the equivalent of two-fifths of a residence unit—the smallest fraction that will be recorded by the Graduate School toward fulfillment of residence requirements. Detailed information concerning extramural courses and registration procedures may be obtained from the Division of Extramural Courses, B-20 Ives Hall.

## EXAMINATIONS

The Special Committee conducts the examinations that are required for the degree. At the discretion of the Special Committee these examinations may be entirely oral or both oral and written. The following examinations are required:

For the Master's degree: a final examination, which under certain conditions may be combined with the Admission to (Ph.D.) Candidacy Examination.

For the doctoral degrees: (1) A comprehensive Admission to Candidacy Examination for formal admission to doctoral candidacy. This examination may not be taken until two units of residence credit have been accumulated and is normally taken in the second or third year. Two terms of residence must be credited after this examination. (2) A final examination, which is primarily concerned with the doctoral dissertation.

In Fields that so desire, the Special Committee may, after the Admission to Candidacy Examination has been taken, nominate the student for a Master's degree without the requirement of a thesis whether or not admission to candidacy has been approved. The degree would be awarded after the completion of four units of residence credit.

In some Fields a qualifying examination is given at an early date to determine the student's fitness for undertaking advanced study and to enable the Special Committee to plan a program which will make him familiar with the requisite knowledge and techniques of his chosen field of study.

When the candidate has completed the thesis, he presents it to the Special Committee at the final thesis examination. This examination is oral and covers subject matter related to the thesis topic.

## FOREIGN LANGUAGE REQUIREMENTS

Each Field of instruction has its own foreign language requirements which it considers most useful to the particular area of study. Any Special Committee may, at its discretion, require knowledge of foreign languages beyond the announced requirements.

Candidates required by Fields to demonstrate a reading ability in French, German, Russian, or Spanish must pass the Graduate School Foreign Language Test given by the Educational Testing Service, Princeton, N.J. 08540, and administered by the Graduate School. A

charge is made to cover the cost of administering each test. As an alternative, candidates may pass the reading part of the CEEB college language test with a score satisfactory to the Division of Modern Languages. Students who take examinations in languages other than French, German, Russian, or Spanish or in a speaking knowledge of any language, should arrange with the Graduate School Office for assignment to a suitable examiner. Arrangements to demonstrate a higher level of proficiency in a foreign language as required by some Fields may be made at the Graduate School Office.

A student may petition the Dean to transfer a language examination taken elsewhere to his record at Cornell.

Courses designed to aid graduate students in learning how to read French, German, Russian, and Spanish are given by the Division of Modern Languages in cooperation with the Graduate School Faculty.

## THESIS

Candidates for the degrees of Master of Arts or Master of Science are required to submit a thesis in fulfillment of the requirements for the degree. In some fields a thesis is also required for professional Master's degrees. Candidates for the doctoral degree must complete a thesis which constitutes an imaginative contribution to knowledge. The faculty requires publication of Ph.D. theses by abstract or microfilm.

## FINANCIAL SUPPORT

Extensive financial support is available to Cornell graduate students. Approximately 3,000 of the 3,300 graduate students have financial support in the form of fellowships, teaching fellowships, and research assistantships.

Since the demands of graduate study are so great, students are discouraged from trying to obtain financial support through employment outside their academic interests.

No special forms are available for financial aid. The applicant should check the type or types of appointment for which he wishes to be considered on the application for admission form.

## TEACHING FELLOWSHIPS

The duties of a teaching fellow normally involve classroom and laboratory instruction of undergraduates and, as such, play a major role in the educational process and the academic atmosphere of the University. Since a large majority of Cornell's graduate students eventually seek a career in teaching, the experience gained from these appointments is an invaluable part of the student's development. In most fields

of study students are encouraged to spend some time in teaching, and in a few fields the faculty believe the experience so important that they require it of all students in doctoral programs. An appointment as a teaching fellow is usually in the student's major field or in one that is closely related. The duties require from ten to twenty total clock-hours a week of the student's time, depending on the field. A teaching fellow whose duties are in his major field of interest and do not exceed twenty hours is eligible for full residence credit. The remuneration varies widely, but it is usually from \$1,900 to \$2,700 for an academic year and may be supplemented by a scholarship which covers tuition and general fees. A special summer fellowship program is also available for teaching fellows. Because of possible problems in communication with undergraduates, applicants from non-English-speaking countries are not normally appointed as teaching fellows in their first year at Cornell. Teaching appointments are made by department chairmen. Applications for these positions should be made to the Field Representative of the field offering the major subject of interest to the student.

## RESEARCH ASSISTANTS

The duties of a research assistant involve work on a research project. The work performed is frequently applicable to the student's thesis research and is under the direction of the chairman of his Special Committee. The student is required to spend twenty hours a week, but if the research is in the field of his major interest he is able to acquire full-time residence credit. In many fields of study such appointments are normally made after the student has completed at least one year of graduate study.

## FELLOWSHIPS

A fellowship ordinarily is awarded in open competition to a full-time student who is a candidate for a higher degree (usually a Ph.D.), primarily on the basis of scholastic ability and promise of achievement as a graduate student. However, if the combined anticipated income of the student and his spouse for the year of September 1, 1969, to September 1, 1970, exceeds \$8,000, the fellowship may be adjusted accordingly. The award is made as a tax-exempt gift, and it usually covers not only tuition and general fees but may also provide a substantial stipend for living expenses during tenure. A student who holds a fellowship is free to select his own research project, subject to the approval of his Special Committee, and his primary responsibility is to pursue his studies for his degree. The award of the fellowship does not obligate the holder to render services to the University, except that in certain fields some teaching is required of all graduate students for the sake of experience and training, nor is the holder of a fellowship committed in any way with respect to future employment. The holder of a fellow-



ship may accept no other appointment or employment without permission of the Fellowship Board; however, teaching responsibilities will usually be approved as a routine matter if they contribute to the student's graduate program and do not exceed ten clock-hours of work per week.

The number of academic-year fellowships awarded by the Graduate School is so extensive that it is impractical to present a listing. (See also Summer Fellowship Support, p. 16.) Many other fellowships are offered to students majoring in certain fields of study, and some of these are noted in the descriptions of the fields.

A new program has been initiated at Cornell for students in the humanities and in selected fields of the social sciences (Anthropology, Economics, Government, Linguistics, Psychology, and Sociology). Its aim is to reduce the time required for a Ph.D. degree. This is to be accomplished through a greatly enlarged program of support, without any sacrifice in the academic standards or requirements for the degree. Incoming students in the Fields covered by the program will be guaranteed support for four full years, including the summer following the first academic year. In most cases, there will be fellowship support for three of the years, with increasing stipends accompanied by full tuition and general fees. One year, or in a few cases up to two years, of teaching fellowship will provide both support and valuable experience and training. Dependency allowances will be available. About 90 per cent of those in the program will be given modest summer scholarships to enable them to continue their studies throughout the year.

Many private and federally supported fellowships are also administered by the Graduate School. National Science Foundation Traineeships, as well as National Defense Education Act (NDEA) Title IV Fellowships, are available to U.S. citizens. The application deadline for these is February 1 for the following academic year; candidates for these fellowships are nominated by the Field, having been chosen from among those students applying. NDEA Title IV Fellowships offer three years of support to doctoral students who intend to enter a teaching career. (Since completion of a Ph.D. program at Cornell normally requires four years, and because the program is aimed at prospective teachers, NDEA Fellows are normally expected to gain teaching experience and have support during one of the years as teaching fellows.)

The purpose of the NDEA Title VI (NDFL) Fellowship program is to provide encouragement to individuals taking advanced training in languages and in associated area studies designated as being of critical importance to the United States. For area studies, see pp. 32-42. Applicants who are interested in NDFL Fellowship support must so indicate when requesting their application materials for admission. National Institutes of Health Traineeships are available and are offered by fields which have been awarded such grants.

A space is provided on the admission application form in which the student may indicate the type of support for which he wishes to be considered. No special fellowship application form is required.

Prospective graduate students should also consider applying for

fellowships awarded on a national basis by the National Science Foundation, the Atomic Energy Commission, the Public Health Service, the Woodrow Wilson National Fellowship Foundation, and the Ford Foundation. These programs have deadlines for applications, some as early as December 1. Applicants should check on the date pertinent to the fellowship. In some cases it is possible for winners of NSF and AEC awards and for PHS Fellows to hold half-time appointments as teaching fellows for an additional stipend.

New York State provides several forms of financial support. The Herbert H. Lehman Fellowship program is open to applicants from all states whose interest is in social sciences or public or international affairs. These Fellowships are awarded on a competitive basis and may be used only in New York State institutions. Lehman Fellowships provide each recipient with \$4,000 for the first year of graduate study and \$5,000 for each subsequent year. New York State residents are eligible for Regents College Teaching Fellowships or Regents Fellowships for Doctoral Study in Arts, Science, and Engineering. Any of these must be applied for by December 1 on forms obtained from the Regents Examination and Scholarship Center, New York State Education Department, Albany, New York 12224.

As agreed upon by some of the members of the Council of Graduate Schools in the United States, the regular time for notification of award from Cornell of fellowships and scholarships for the succeeding academic years is April 1. *All fellowship and scholarship applications received by February 1 will be considered for April awards*, and every effort will be made to notify each applicant approved for award no later than April 6 as to whether he has a fellowship or is named as an alternate. It is hoped that the awardees will notify the Graduate School no later than April 15 of their acceptance or rejection of the award. Failure to do this by April 15 will be considered a declination. Applications received after February 1 will be considered only if vacancies occur.

## SUPPORT IN THE HUMANITIES

Recognizing that the availability of financial support for continuing graduate students in the area of the Humanities is less than in other areas, Cornell has made a particular effort to compensate for this inequity by a special Cornell-supported program. Students in doctoral programs in the Humanities area who enter with financial support from Cornell, or with nationally awarded fellowships, are guaranteed support in the form of an assistantship or a fellowship for a four-year period, provided they are making satisfactory progress toward the doctoral degree.

## SUMMER FELLOWSHIP SUPPORT

The Graduate School Faculty believes that graduate education, in contrast to undergraduate programs, should be on a year-round basis to

enable students to obtain their degrees in a reasonable period of time. The majority of Cornell Ph.D. students are, therefore, supported over the summer period through research assistantships and fellowships. Normally the summer period is devoted to informal study and research rather than to course work, and no tuition or fees are charged.

Two extensive summer fellowship programs based on financial need are noteworthy. One involves awards to those students who have been full-time teaching fellows. The other involves fellowship support to students who are in the final stages of their thesis preparation. It is expected that some 250 summer fellowships will be awarded for the summer of 1969 under these two programs. Another 1,300 students will be supported as research assistants, and 250 students will be on twelve-month fellowships.

## RESIDENCE HALL ASSISTANTSHIPS

Assistantships in University residence halls are available for men and women graduate students in any academic field. They are most appropriate for graduate students who desire experience in working with undergraduate students and University staff while contributing financially to their own study.

In the women's area eighteen assistantships are available, offering living expenses and a yearly stipend. Particulars and application forms may be obtained by writing to the Office of the Dean of Students, 133 Day Hall. Personal interview is desirable but not always required.

In the men's housing area two types of positions are available, the Head Residency and Resident Advisorship. There are Head Residencies for single and married men. A Head Resident receives his apartment, a stipend of \$700, payment of one-half tuition and fees, and board package which varies according to his marital status. Resident Advisorships are available to single men. A Resident Advisor receives his room, a \$500 stipend, payment of one half tuition and fees and twenty meals weekly in University facilities. There are eight Head Residencies and Resident Advisorships. These men work in counseling and guidance, programming and direct the activities of Undergraduate Residence Counselors.

Applications should be addressed to the Office of the Dean of Students, 133 Day Hall. The deadline for application for positions in men's dormitories is January 15. A personal interview is required for acceptance for a position.

## LOANS

Only graduate students duly registered in a degree-granting program are eligible for loans. This does not include provisional or noncandidate students.

Cornell utilizes university, state, and National Defense Loan programs. The total amount of loan recommended, regardless of source, is

based upon the financial need of the student as analyzed by the University Committee on Financial Aid.

Applications are available at the Office of Scholarships and Financial Aid, 105 Day Hall. State loan applications may also be obtained at this office.

## PART-TIME EMPLOYMENT

Additional opportunities for part-time work are often available in connection with departmental research projects or other activities. Applications for this type of work should be made directly to the department concerned. If a candidate is employed in research or other work closely allied to his academic interest, he may find such employment academically valuable.

Progress in candidacy is difficult when a student attempts to support himself wholly or partially by work unrelated to his studies. It usually is sounder economy to borrow from the Office of Scholarships and Financial Aid and keep employment to a minimum. However, the University maintains a part-time student employment service in that office.

## EMPLOYMENT OPPORTUNITIES FOR WIVES OF GRADUATE STUDENTS

Cornell University offers many nonacademic positions for working wives through the Personnel Division, B-12 Ives Hall. Types of work include secretarial and clerical work, work for technicians in the various laboratories, library work, limited nursing positions, and some administrative positions. Applications may be made through the Personnel Division upon arrival on campus. Applicants for academic positions should apply to the specific departments in which they are interested.

In addition to the University positions, the Ithaca area offers opportunities for similar positions in small industrial plants, Ithaca College, the local hospital, and various businesses, as well as for teaching positions in the public school system and some professional positions in service agencies. Applicants should go to the New York State Employment Office for further information regarding these opportunities.

## GENERAL INFORMATION

### ACTIVITIES FOR GRADUATE STUDENTS

Cornell is in a small academic town in central New York State. It has the advantages of a small-town atmosphere but at the same time has many cultural aspects that rival those of any large city. A significant concert program brings internationally famous artists to Ithaca. Dramatic programs, talks by visiting lecturers, and art exhibitions fill the

weekly calendar of the University and present such a wide choice of events that a student cannot possibly attend all in which he is interested.

There are places for graduate students in many extracurricular activities shared by undergraduates; among others are intramural sports, drama, Glee Club, Sage Chapel Choir, publications, music, and folk dancing. A Graduate Student Activities Committee is active in scheduling weekly social events. A Graduate Wives' Club has had a long tradition of activity for the wives of graduate students. Willard Straight Hall and the Sage Graduate Center provide facilities for graduate groups and aid in planning special functions for them.

Cornell United Religious Work (CURW) includes a range of activities for graduate students. Its offices are in Anabel Taylor Hall, which serves as a headquarters for chaplains who represent several denominations and who may be consulted by students.

Cornell's location in the Finger Lakes Region of New York State stimulates outdoor activity. Many swimming and boating facilities are available. In addition, Cornell operates a private eighteen-hole golf course; indoor and outdoor swimming facilities; indoor skating rink; tennis, handball, and squash courts; gymnasium; and riding stables all of which are open to graduate students. A variety of ski resorts also operate near by.

Almost all fields of study sponsor weekly seminars for their faculty and graduate students.

## COUNSELING

The University maintains a variety of counseling services available to graduate students. A student's primary academic counselors are the members of his Special Committee.

Other counselors who are able to help in matters of various kinds will be found in the Office of the Dean of Students, the Office of Scholarships and Financial Aid, the International Student Office, the Gannett Medical Clinic, and the Sage Graduate Center.

## INTERNATIONAL STUDENTS

Cornell has, since its founding, welcomed students from abroad. Currently 1,068 foreign students representing 86 countries are pursuing study in a variety of fields.

In addition, each year over one hundred faculty members spend some time abroad in study and research, often in close association with foreign universities. This creates within the University community opportunities for scholars from other countries to meet and exchange ideas with members of the Cornell faculty, who often have first-hand knowledge of several countries and understand and appreciate a variety of cultures.

Special study programs within the Graduate School permit study in depth of particular areas such as Africa, Asia, Southeast Asia, Latin

America, and the Near East. Students from those areas have an opportunity to contribute to such programs.

The Ithaca community is in a natural setting which allows for enjoyment of many recreational activities. In addition, varied cultural and intellectual activities are sponsored by the University. Tours of the community are conducted at the beginning of the fall semester. A group of Cornell faculty and Ithaca families maintain a Host Family Program, in which foreign students are invited to share in some aspects of American family life in the Ithaca community. With the University population a varied one, the community itself, although not large, tends to have a more cosmopolitan atmosphere than most other small cities, and the student can usually find an outlet for a wide variety of interests.

The University maintains an International Student Office at 142 Day Hall. Students from abroad are invited to consult the staff of that office on any questions they may have. The office works in close association with academic advisers and sponsors, and also with persons involved in a number of student and community programs in efforts to enrich the international and cultural life of Cornell. Students are asked to report to this office upon arriving in Ithaca.

## HEALTH REQUIREMENTS ON ENTRANCE

The following health requirements for entering graduate students have been adopted by the Board of Trustees of Cornell University. Failure to fulfill these requirements may result in loss of privilege of registering the following term. The responsibility for fulfilling these requirements rests upon the student.

**IMMUNIZATION.** A satisfactory certificate of immunization against smallpox, on the form supplied by the University, must be submitted before registration. It will be accepted as satisfactory only if it certifies that within the last three years a successful vaccination has been performed. If this requirement cannot be fulfilled by the student's home physician, opportunity for immunization will be offered by the Cornell medical staff during the student's first semester, with the cost to be borne by the student. If a student has been absent from the University for more than three years, immunity will be considered to have lapsed and a certificate of revaccination must be submitted.

It is strongly recommended by the University Health Services that all graduate students have immunization against tetanus before entering the University. All graduate students may, however, obtain initial and all booster tetanus toxoid immunizations at the Gannett Clinic for a nominal charge.

**HEALTH HISTORY.** Graduate students, when accepted, must submit *health histories* on forms supplied by the University. These should be returned promptly to the Gannett Medical Clinic. A University physician will review the material before it becomes part of the student's permanent health record. All information given is confidential. After

arrival at Cornell, if the medical history indicates a need, a student will be given an appointment to consult a physician at the Clinic. When a student has been away from the University for more than a year, he must, upon reentrance, submit an interim health history on a University form.

**X RAY.** Every student is required to have a chest x ray. Opportunity to satisfy this requirement is given during the student's first week on campus. The cost of the x-ray examination is included in the General Fee. When a student who has been away from the University for more than a year wishes to reenter, he must at his own expense, once more fulfill the chest x-ray requirement.

## HEALTH SERVICES AND MEDICAL CARE

Health services and medical care for students are centered in two Cornell facilities: The Gannett Medical Clinic (outpatient department), 10 Central Avenue, and the Sage Hospital.

Students are entitled to unlimited visits at the Clinic. Appointments with individual doctors at the Clinic may be made by calling or coming in person. (An acutely ill student will be seen promptly whether he has an appointment or not.) Students are also entitled to laboratory and x-ray examinations indicated for diagnosis and treatment, hospitalization in the Sage Hospital with medical care for a maximum of fourteen days each term, and emergency surgical care.

On a voluntary basis, insurance is available to supplement the services provided by the General Fee. For further details see the *Announcement of General Information*. If, in the opinion of the University authorities, the student's health makes it unwise for him to remain in the University, he may be required to withdraw.

If a student prefers to consult a private physician rather than go to the Clinic, or to have the services of a private doctor while a patient in Sage Hospital, he must bear the cost of these services.

## LIVING ARRANGEMENTS

**DORMITORY ACCOMMODATIONS.** The University has established Sage Hall as a graduate residential center. Its dormitory facilities accommodate approximately seventy-five men in the north side of the building and 115 women in the south side. The Graduate Center, which is available for use by graduate students and faculty, also contains a cafeteria seating 200, study rooms, and lounges. In addition, Cascadilla Hall has accommodations for approximately 160 single graduate men.

Applications for dormitory accommodations may be obtained any time after January 1 for the coming academic year by writing the Department of Housing and Dining Services, 223 Day Hall.

**FAMILY ACCOMMODATIONS.** The University, through the Department of Housing and Dining Services, has three apartment developments

for married students and their families. They are Cornell Quarters, Pleasant Grove Apartments, and Hasbrouck Apartments, with total housing for about 450 families. All apartments are unfurnished. For further information and application, write to the Department of Housing and Dining Services, Room 223, Day Hall.

**OFF-CAMPUS HOUSING.** Faculty legislation requires that all students live in Cornell-approved housing. The Department of Housing and Dining Services in Room 223, Edmund Ezra Day Hall, functions as a bureau of information and maintains files of voluntarily listed accommodations for use of students and staff members who call at the office. Because the list of available accommodations is constantly changing, it is not practical to mail listings, nor is it feasible to maintain a waiting list of persons seeking accommodations.

## MOTOR VEHICLES

The University does not encourage student use of motor vehicles but recognizes that in certain cases there may be important reasons why a student needs a motor vehicle. University regulations apply to all types of motor vehicles, including automobiles, motorcycles, motor bikes, and motor scooters.

Every student who owns, maintains, or for his own benefit operates a motor vehicle in Tompkins County, must register it with the Safety and Security Division, even though that vehicle may be also registered by faculty, officers, or employees. All students must register motor vehicles within the prescribed time for University registration at the beginning of the fall term (*exception*: students who are not then subject to this rule but later become subject to it must register vehicles within five days after becoming so subject). Nonregistered vehicles may not be parked on campus at any time. Students entering the University for the spring semester or reentering after a period of absence must register motor vehicles with the Safety and Security Division at the time of, or within the time for, general registration.

Every student who has a motor vehicle must comply with the following requirements: (1) the student must be legally qualified to operate a motor vehicle in New York State; (2) the vehicle must be registered in New York State or legally qualified to be operated on the highways of New York State; (3) the vehicle must be effectively insured against public liability for personal injury and property damage for the minimum of \$10,000—\$20,000—\$5,000, for the duration of such registration and while the vehicle is under the control of the registering student; (4) the registration fee covering the fall and spring terms, or any part thereof, is \$4.00 and is due and payable in the Treasurer's Office on the same date as tuition and other fees. In case of late registrants, the fee will be due within a week after such registration. A fine is levied if the vehicle is not registered within the specified time.

No student may park his motor vehicle on the campus from 8 A.M. to 5 P.M. Monday through Friday, or from 8 A.M. to 1 P.M. Saturdays.



Certain areas are restricted twenty-four hours a day; such areas include "no parking" zones, dormitory parking areas, and areas listed as limited at all times to holders of specific permits.

Special area parking permits are issued only after careful consideration by the Safety and Security Division Office. Extenuating circumstances (physical disabilities, etc.) are the basis for the issuance of these permits.

The student's registration in the University is held to constitute an agreement on his part that he will abide by all its rules and regulations with regard to traffic and parking or suffer the penalty prescribed for any violation of them.

Correspondence regarding motor vehicles should be addressed to the Board on Traffic Control, G-2 Barton Hall.

## CAREER, SUMMER PLANS, AND PLACEMENT CENTER

The Career, Summer Plans, and Placement Center at 14 East Avenue is a clearing house for jobs in business, industry, government, and teaching; as well as study programs leading to the professions. It serves as an information center for careers, teacher placement, fellowships, techniques of job hunting, and summer experiences (work, study, travel, service projects). More than a thousand recruiters visit the campus each year representing employers and graduate schools. Students and faculty may be kept up to date on the activities of the Center by registering to receive its *Newsletter*. Alumni may be served by either the *Job Bulletin* or the *Registrants Available Bulletin*. Through the support and cooperation of the Cornell Club of New York and the Cornell Society of Engineers, a placement office is maintained in New York City primarily for alumni living in that area.

## TUITION AND FEES

Tuition and fees<sup>1</sup> become due when the student registers. Any student who fails to pay his tuition, fees, and other indebtedness to the University at the Treasurer's Office within the prescribed period of grace will be dropped from the University unless the Treasurer has granted him an extension of time to complete payment. The Treasurer is permitted to grant such an extension when, in his judgment, the circumstances of a particular case warrant his doing so. For any such extension the student is charged a fee of \$5.00. A reinstatement fee of \$10.00 is assessed against any student who is permitted to continue or return to classes after being dropped from the University for default in payments. The assessment may be waived in any instance for reasons

<sup>1</sup> All statements in this section are prepared by the Treasurer, who alone is authorized to interpret them.

satisfactory to the Treasurer and the Registrar when such reasons are set forth in a written statement.

Students registering at any time during the last ten weeks of any term are required to pay tuition at the rate of 10 per cent of the regular tuition of the term for each week or fraction of a week between the day of registration and the last examination day of the term.

*Tuition or fees may be changed by the Trustees at any time without previous notice.*

## FEES PAYABLE BY GRADUATE STUDENTS

### Registration Deposit

A deposit of \$35.00 must be made by every applicant for admission after the applicant has received notice of acceptance, unless the candidate has previously matriculated as a student at Cornell University. This deposit is used at the time of first registration to pay the matriculation fee, chest x ray, and examination-book charge, and covers certain expenses incidental to graduation if the student receives a degree. The deposit will not be refunded to any candidate who withdraws his application after May 10 or after fifteen days of his admission approval. This fee is *not* covered by university fellowships, scholarships, or assistantships.

### Tuition

Tuition is \$200 a term for all students registered in the Graduate School whose major chairman is on the faculty of the statutory divisions<sup>2</sup> of the University. Those with major work in the School of Nutrition, the Field of Education, and the Division of Biological Sciences also pay \$200 a term. All students in other divisions must pay tuition of \$847.50 a term. Tuition is payable at the beginning of each term.

Upon recommendation by the appropriate college dean and by action of the Controller, for each appointment in a statutory school or college, waiver of tuition in the Graduate School may be made to a member of the teaching or scientific staff, whose major field of study is in a statutory school or college.

Assistants in statutory schools or colleges who are on twelve-month appointments and who are registered for Summer Research for credit in the Graduate School may be recommended for waiver of tuition during the summer period under the above limitations. This waiver of tuition does not apply if the student registers in the Summer Session or is not doing productive work for the department.

Any student who is to receive less than full residence credit because of his employment should apply for proration of tuition on forms procurable at the Graduate School Office. *Tuition is based on residence eligibility.* See pp. 9-11.

<sup>2</sup> The statutory divisions are the Veterinary College, the Colleges of Agriculture and Home Economics, and the School of Industrial and Labor Relations.

## General Fee

A fee of \$275.00, payable at the beginning of each term, is required of each student registered in the Graduate School whose major chairman is on the faculty of one of the statutory divisions,<sup>3</sup> the School of Nutrition, the Field of Education, or the Division of Biological Sciences. All others pay a fee of \$252.50. This General Fee contributes toward the services supplied by the libraries, Clinic and Hospital, and the student union in Willard Straight Hall, and pays a portion of the extra cost of laboratory courses and general administration.

A student who is regularly registered in the Graduate School for either one or both terms of the academic year and has paid the above fee is entitled to these services while in residence during the summer immediately following the academic year without payment of an additional General Fee. If such a student registers with the University during the summer, he is liable for payment of any tuition and other fees, and must present his ID card at the time of payment of these charges in order to claim exemption from payment of the General Fee.

A graduate student who returns to the University to present his thesis and to take the final examination for an advanced degree, all other work for that degree having been previously completed, must register as a "Candidate for Degree Only" and pay a fee of \$35.00.

## Other Fees

**THESIS FEE.** Each doctoral candidate must pay \$30.00 at the time of depositing the approved thesis and abstract in final form. This fee covers the cost of preparing a master microfilm of the entire thesis; of publishing the abstract in the bimonthly periodical, *Dissertation Abstracts*; of mailing the microfilm and abstract to the microfilm publisher; and of binding both copies of the thesis for deposit in the University Library.

**LIMITED REFUNDS.** Part of the tuition and General Fee will be refunded to students who officially withdraw or take a leave of absence during the first nine weeks of a term. A student arranges for a leave of absence or withdrawal at the Graduate School Office. Students who withdraw are charged tuition and the General Fee at the rate of 10 per cent for each week or fraction of a week from registration to the effective date of withdrawal. No charge is made if the student withdraws within six days of registration. No part of the registration or matriculation fee is refundable.

**SUMMER SESSION.** Graduate students who attend classes in the Summer Session must register both in the Graduate School and in the Summer Session; they must pay the tuition and fees listed in the *Announcement of the Summer Session*.

<sup>3</sup> The statutory divisions are the Veterinary College, the Colleges of Agriculture and Home Economics, and the School of Industrial and Labor Relations.

**SUMMER RESEARCH.** Students registered for Summer Research pay one half of the General Fee for a registration period of not more than eight weeks and the full fee for a registration period of over eight weeks unless they were regularly registered in the Graduate School during the previous academic year. For those students eligible for and desiring residence, a prorated tuition is charged in accordance with the fraction of a residence unit to be earned, based on the tuition in effect for the subsequent academic term.

**IN ABSENTIA.** A graduate student registered *in absentia* will pay a fee of \$35.00 each term.

## ADVANCED PROFESSIONAL DEGREES

Advanced professional degrees are designed as preparation and training for a special profession.<sup>4</sup> The admissions, requirements, and curricula for such degrees, as approved by the Graduate Faculty, are announced by the faculty of a professional school or college, which, for this purpose, acts as a Division of the Graduate Faculty. Degrees are awarded upon recommendation of the Division to the Graduate Faculty. Detailed information regarding admission or academic requirements for any professional degree is included in the *Announcement* of the separate school or college in which the degree is offered. Inquiries addressed to the Graduate School will be forwarded to the proper official. The professional degrees listed below are approved by the Graduate Faculty.

### ARCHITECTURE, FINE ARTS, CITY AND REGIONAL PLANNING

The following three degrees are administered by the Division of Architecture, Fine Arts, and Planning of the Graduate School. Inquiries should be addressed to the listed professor.

For more detailed information on these degrees, as well as those in architectural structures, architectural history, and art, see also the *Announcement of the Graduate School: Humanities*.

**MASTER OF ARCHITECTURE (M.Arch.).** Training in urban design. Only graduates of a five-year professional program in architecture or

<sup>4</sup> The following are advanced degrees which are also first degrees of a school or college and therefore are not subject to the jurisdiction of the Graduate Faculty. For information regarding them, address the school or college indicated.

Master of Engineering (Aerospace)	.....	Graduate School of Aerospace Engineering
Master of Business Administration	}	.....Graduate School of Business and Public Administration
Master of Public Administration		

Doctor of Law	.....	Law School
Doctor of Medicine	.....	Medical College, New York City
Doctor of Veterinary Medicine	.....	Veterinary College

graduates of a program in city planning or landscape architecture are admitted as candidates. (Professor Colin Rowe.)

**MASTER OF FINE ARTS (M.F.A.).** Advanced training in the practice of painting, sculpture, or graphic arts. (Professor Jason Seley.)

**MASTER OF REGIONAL PLANNING (M.R.P.).** Training for a professional career in the field of city planning or regional planning. (Professor Kermit C. Parsons.)

## EDUCATION

Two professional degrees are administered by the Field of Education of the Graduate School. The programs leading to each of the degrees include courses, seminars, projects, and investigations which will develop the student's ability to perform acceptably the professional duties required of the several types of educational specialization.

**MASTER OF ARTS IN TEACHING (M.A.T.).** This program is designed for and limited to those preparing for teaching in elementary and secondary schools. The student and his Special Committee will select those courses and seminars in his teaching specialty and in Education which are deemed most appropriate for developing competence as a teacher. The student will be required to demonstrate his or her teaching skill in a supervised field experience. Completion of a twelve-month program, or two and two-fifths residence units is required. Graduates of a teacher-training program are not eligible for this degree.

**DOCTOR OF EDUCATION (Ed.D.).** The program for this degree is designed to prepare the candidate within a broad cultural context for positions of professional leadership in education. The program of studies must include advanced work in each of the following: educational psychology, history or philosophy of education, educational measurement and statistics, and research in education. At least fifteen hours of credit must be earned in courses other than those in professional education. A minimum of sixty-five credit hours beyond the Bachelor's degree is required, of which thirty-five hours should be completed beyond the Master's degree or its equivalent. A candidate is required to complete a minimum of five residence units beyond the Bachelor's degree and a year of directed field experience.

## Professional Teaching

**MASTER OF SCIENCE FOR TEACHERS (M.S.T.).** This is a coordinated program of training in the biological and physical sciences for practicing teachers. Each degree candidate must satisfy a broad core program in mathematics and science and complete advanced work in his selected Field of study. This degree is administered by the Divi-

sion of Professional Teaching of the Graduate School. Detailed information may be obtained from the Graduate School Office, Sage Graduate Center.

## ENGINEERING

The degree of Master of Engineering is administered by the Engineering Division of the Graduate School. Specially oriented graduate programs of study are in the areas of agricultural, chemical, civil, electrical, industrial, materials, mechanical, and nuclear engineering, and in engineering physics. The following titles designate the professional Masters' degrees offered in engineering: Master of Engineering (Agricultural), Master of Engineering (Chemical), Master of Engineering (Civil), Master of Engineering (Electrical), Master of Engineering (Engineering Physics), Master of Engineering (Industrial), Master of Engineering (Materials), Master of Engineering (Mechanical), Master of Engineering (Nuclear). The Graduate School of Aerospace Engineering administers the Master of Engineering (Aerospace) degree program.

The general requirements for the degrees listed above are:

1. A minimum of thirty credit hours of advanced technical course work in the specific field or in related subjects.
2. A minimum of three credit hours (included in the above) of engineering design experience involving individual effort and formal report.
3. A minimum grade point average of 2.5 and a minimum final grade of C minus for all courses counting toward the degree.

There are no residence requirements, although all course work must, in general, be completed under Cornell University staff instruction. The degree requirements must normally be completed within a period of four calendar years.

Graduates of Cornell University who hold Bachelor of Engineering degrees may be granted up to fifteen hours credit for advanced courses taken during their fifth undergraduate year, provided they enter the Master of Engineering program not later than the fall term following the sixth anniversary of their receiving the Bachelor of Engineering degree.

The *Announcement of the College of Engineering* should be consulted for further details on the professional Masters' programs in the various fields.

## ENGLISH

**MASTER OF FINE ARTS (M.F.A.).** The degree of Master of Fine Arts in creative writing is designed to prepare candidates for careers in professional writing or in the teaching of creative writing. The program is administered by a specially appointed committee of the Department of English, acting as a Division of the Graduate School.

## INDUSTRIAL AND LABOR RELATIONS

**MASTER OF INDUSTRIAL AND LABOR RELATIONS (M.I.L.R.).** The four-semester program leading to this degree provides a basic course of graduate study for those with professional interests in industrial and labor relations and further provides limited opportunities for specialized professional study where broad competence has been established. This degree is administered by the Division of Industrial and Labor Relations of the Graduate School. More information may be obtained by writing to the Graduate Field Representative, School of Industrial and Labor Relations, Ives Hall.

## LAW

The following two degrees are administered by the Division of Law of the Graduate School. The *Announcement of the Law School* should be consulted for a complete description of the program and requirements.

**MASTER OF LAWS (LL.M.).** This degree is intended primarily for the student who desires to increase his knowledge of the law by working in a specialized field.

**DOCTOR OF THE SCIENCE OF LAWS (J.S.D.).** This degree is intended primarily for the student who desires to become a proficient scholar by original investigation into the functions, administration, history, and progress of law.

## MUSIC

**DOCTOR OF MUSICAL ARTS (A.Mus.D.).** This degree is appropriate for mature composers who seek further professional training as well as knowledge of the other arts and humanities, both to enrich their creative perspectives and to prepare them for the teaching of composition and theory at the university level. It is administered by the Department of Music, acting as a Division of the Graduate School for this purpose.

## NUTRITIONAL AND FOOD SCIENCE

The following two degrees are administered by the faculty of the Graduate School of Nutrition acting as a division of the Graduate School. More information may be obtained by writing to the Secretary, Graduate School of Nutrition, Savage Hall.

**MASTER OF NUTRITIONAL SCIENCE (M.N.S.).** This program emphasizes fundamental study in the basic biological sciences that can

lead to specialization in such areas as nutritional biochemistry, human and clinical nutrition, experimental or animal nutrition, and public health and international nutrition. The program is open to students who have had no previous course work in nutrition. For candidates interested in the biological sciences, the program serves as a valuable preliminary for graduate study for the Ph.D. degree in such areas as biochemistry and physiology, as well as human or animal nutrition.

**MASTER OF FOOD SCIENCE (M.F.S.).** The fundamental sciences, chemistry, biochemistry, and bacteriology, that are involved in food processing and utilization, are emphasized. Electives are available to meet individual needs in engineering, economics, marketing, business administration, and international programs. The specialized training serves as a preparation for technical work as related to the food industry or for more advanced graduate study.

The *Announcement of the Graduate School of Nutrition* should be consulted for further details on the professional Master's degree programs.

## THEATRE ARTS

**MASTER OF FINE ARTS (M.F.A.).** The degree of Master of Fine Arts in theatre arts is intended for students who wish to increase their professional competence as actors or directors through a studio-oriented program. It is administered by the Department of Theatre Arts, acting as a Division of the Graduate School for this purpose.

## VETERINARY MEDICINE

**DOCTOR OF SCIENCE IN VETERINARY MEDICINE (D.Sc. in V.M.).** This degree is characterized by a professional rather than a general research objective, and it is designed especially for experienced persons in the basic and clinical sciences who need more specific, advanced, scientific, and professional knowledge in order to equip themselves for careers in teaching and research. This degree is administered by the Division of Veterinary Medicine of the Graduate School.

## SPECIAL RESOURCES FOR RESEARCH AND ADVANCED STUDY

The descriptions below are limited to major general facilities at the service of graduate students in any of a variety of fields of instruction. In addition, substantial collections and facilities, in many instances unique, have been assembled for the use of graduate students. Although the facilities cannot be described adequately in this *Announcement*,



some of them are mentioned in the statements given under the Fields of Instruction on pp. 53 ff.

## CORNELL UNIVERSITY LIBRARIES

The libraries are among the principal facilities in the University's program of graduate studies. The total number of volumes at Cornell is now over 3,000,000 and that figure increases by about 175,000 each year. For the convenience of students and faculty, the holdings are organized into a controlled system of distinct libraries. Some of the libraries are large; some have limited holdings. Some are general; some selective. Each library, whether within one of the colleges or housed in a building of its own, is situated where its books and its facilities lie most easily available to those who use them most. The libraries, whatever their nature, have been developed over many years by scholarly librarians and professors with the view of achieving breadth and depth in the central libraries, utility and coherence in the specialized ones.

The University's libraries offer support for graduate studies at several levels. They provide basic readings in virtually all subjects, collateral studies for classroom and seminar instruction, and highly specialized materials for advanced students. An unusually rich collection of reference works, both modern and antiquarian, expedites both the daily study and dissertational research. Of journals and periodicals, about 35,000 titles are available, most of them in complete runs, some of them in multiple copies, all of them immediately available. Special departments are maintained for maps, microtexts, documents, newspapers and other such collections.

To most graduate students, Olin Library, designed primarily as a research library, becomes the most familiar. Olin Library, completed in 1961, offers every modern library facility for its readers. The building is completely air-conditioned, scientifically lighted, comfortably furnished, and organized for efficient operation. It provides easy access to the book stacks, convenient photocopying facilities, and a comfortable lounge area for graduate students. Congestion is eliminated not only because of architectural design but also because undergraduates have their own open-stack library in a separate building. A graduate student whose work has advanced to the writing stage may apply for use of a carrel adjoining the book stacks in order to facilitate completion of his dissertation. Olin Library is open in term time from 8 A.M. to 12 midnight weekdays, and from 1 P.M. to 12 midnight Sundays.

Within Olin are a number of special collections likely to be of particular interest to advanced students of the social sciences and the humanities. The Department of Rare Books houses several distinguished collections, among them books and manuscripts relating to Dante, Petrarch, Wordsworth, Joyce, Shaw, and other literary figures. The Noyes Collection is rich in American historical documents, especially those pertaining to Lincoln and the Civil War. Students in the social sciences will also find extraordinarily interesting manuscripts and books

in the collections of slavery and abolition, of witchcraft, of the French Revolution, and of the life and times of Lafayette. Long familiar to professional scholars are the Wason Collection on China and the Chinese, the Old Icelandic Collection, and collections on Japan and Southeast Asia. The History of Science collections include the Adelman Library of Embryology and Anatomy, and the library of the French scientist, Lavoisier. The collection of Regional History and Cornell University archives is a manuscript depository with total holdings of more than 14,000,000 items. These manuscripts relate to all aspects of the economic, political, and social history of this region and the areas historically connected with it. Here, too, are the documents and manuscripts relevant to the founding and development of Cornell University. In addition to the collections in Olin Library, many of the college and department libraries also contain materials unique in their respective fields. Curators and reference librarians in all the libraries are available for counsel concerning the availability and use of research materials.

The University libraries in aggregate consist of Olin Library, as mentioned, Uris Library for Undergraduates, the Physical Sciences Library, the Mann Library of Agriculture and Home Economics, and the libraries of the following colleges and schools: Fine Arts, Business and Public Administration, Engineering, Hotel Administration, Industrial and Labor Relations, Law, Medicine (in New York City), and Veterinary Medicine. Added to these are the libraries of academic divisions and departments, together with those of the Agricultural Experiment Station at Geneva, New York.

## INTERNATIONAL STUDIES PROGRAMS

### Center for International Studies

The Center for International Studies has as its primary function the coordination and support of the international activities of Cornell University. In addition to its role as a link between the activities of the specialized programs, the Center endeavors to facilitate and encourage research and teaching dealing with international affairs and to serve as a focal point for their discussion. The Center brings to Cornell visiting faculty, postdoctoral research fellows, and distinguished academic and professional personnel in the area of international affairs who give interdisciplinary courses and seminars. Through the use of the permanent Cornell faculty, the Center is developing a teaching program at the undergraduate and graduate levels where it can usefully add to the regular offerings of separate schools and departments.

Students interested in foreign area studies or in international problems will find that the flexibility of both undergraduate and graduate requirements permits considerable latitude in selecting subjects. Appropriate courses of study can be selected from the regular offerings of various departments of the University. For example, in the College

of Arts and Sciences the Department of Government offers instruction in comparative government, international relations, and international law and organization; in the Department of Economics there are offerings in international economics, economic development, and international trade. The College of Agriculture offers courses in the economics of agricultural development, international agriculture, and rural sociology. The School of Business and Public Administration offers courses in international development and comparative administration. The School of Industrial and Labor Relations offers courses in international and comparative labor relations.

The graduate student seeking specialized foreign-area knowledge may arrange a minor in one of the interdisciplinary area programs: Asian Studies or Latin American Studies. It is also possible for the student to pursue an area interest in African Studies, European Studies, or Soviet Studies.

The continued growth of the international programs has been accompanied by the creation of an outstanding and comprehensive infrastructure of staff, library, language facilities, and other necessary resources.

The work of the Center and of associated programs and activities is more fully described in the Center's *Annual Report of International Studies at Cornell University* and the *Announcement of the Center for International Studies*. Further information may be obtained from the Center's office in 217 Rand Hall.

## African Studies

**ADVISORY FACULTY COMMITTEE ON AFRICAN STUDIES:** William H. Friedland, Chairman; Douglas Ashford, Harold Feldman, Milton Konvitz, Ian Macneil, Chandler Morse, Thomas Poleman, Kathleen Rhodes, Victor Turner.

Cornell University has substantial facilities for graduate study and research on Africa. Many members of the faculty in a variety of fields are qualified by research experience in Africa to provide instruction or guidance to students who wish to specialize in some aspect of African studies, who plan to work there, or who are interested in a general or comparative knowledge of the area. Instruction and training in general linguistics are available for students expecting to deal with tribal peoples, and special courses on particular African languages (e.g., Ibo, Yoruba) have been given in recent years. Courses are regularly offered on the cultures and social systems of Africa and on the problems of economic, political and social development of the area. The University libraries provide a good working collection of books, documents, maps, newspapers, and periodicals on Africa of sufficient scope to enable students and staff to carry on regional research. A representative group of African students is attracted to Cornell each year, most of whom are eager to discuss African life and problems with interested students from other areas.

Inquiries should be directed to Professor William H. Friedland, Chairman, Committee on African Studies, Ives Hall.

## China Program

**FACULTY:** Knight Biggerstaff, Nicholas C. Bodman, Nai-Ruenn Chen, Chuen-tang Chow, John C. H. Fei, Ta-Chung Liu, John McCoy, David Mozingo, Charles A. Peterson, Harold Shadick, Judith M. Treistman, Arthur P. Wolf, Martie W. Young.

The China Program provides comprehensive graduate-level training and sponsors a wide range of research. The faculty represent the following fields: anthropology, economics, government, history, history of art, linguistics and literature.

Graduate students in the program take a major in one of the fields listed above. They are expected at an early stage to attain sufficient mastery of the Chinese language to permit use of Chinese sources in their courses and seminars and in their research.

The focus of much of the research and teaching in the Program is the society, polity, economy, culture, and arts of modern and contemporary China. Students with this concentration are also expected to develop a general knowledge of traditional institutions and culture. Students majoring in history concentrate on medieval or modern China; no chronological limits apply to those in the history of art, linguistics, or literature.

The China Program supports three projects: Political Organization, Social Change, and Personality Development; Economic Development within a Chinese Cultural Setting; and Linguistic Studies in Southeast China and in the Southwest Border Regions. Research Assistantships are available to advanced graduate students working in these areas, and occasionally in other fields as well. London-Cornell Studentships are open to advanced Ph.D. candidates in the social sciences and humanities who are in the China Program. They are tenable for study during an academic year at the London School of Economics and Political Science or at the School of Oriental and African Studies of the University of London. Stipends include air fares and tuition and fees.

London-Cornell Field Research Grants are open to Ph.D. candidates whose interests directly concern problems of social change in East Asia. Grantees may conduct dissertation research in any part of East Asia, and stipends for this purpose include travel and research expenses.

National Defense Foreign Language Fellowships and Foreign Area Training Fellowships are tenable in the Program. Graduate students may also apply for other assistantships, fellowships, and scholarships offered by the University and by its departments.

Additional information on the Program and the various fellowships and awards may be obtained by writing to the Director, China Program, 100-A Franklin Hall.

## Program on Comparative Economic Development

The Program on Comparative Economic Development at Cornell University was founded in 1966 by a group of economists in the Department of Economics, the Department of Agricultural Economics, and the School of Industrial and Labor Relations. Its primary purpose is theoretical and empirical research into the causes and forces of economic development, emphasis being placed on the multiplicity and diversity of forms of the development phenomenon.

Several secondary benefits derive, or are expected to derive, from the activities of the Program. One is the educational feedback in the form of seminars, guest lecturers, and the availability of research scholarships to graduate students in the Department of Economics. Further, arrangements are being made for the establishment of regional research and educational centers in selected focal development countries.

The Program is not restricted to economists. On the contrary, it is hoped that as time goes on cooperation will be obtained from other fields. In fact, the philosophy of a wider basis of development science, not restricted to economics, is intended to become the central strength of the Program.

Additional information may be obtained by writing to Professor Ta-Chung Liu, Director of the Program, Goldwin Smith Hall, Cornell University, Ithaca, New York 14850.

## International Agricultural Development Program

Cornell University provides unusual scope and facilities for graduate-level study and research concerning development of the critical agricultural sector of newly developing nations. An integrated program of research and graduate training is available in the various biological, physical, and social sciences fields which are relevant to agricultural development.

A student preparing for work in international agricultural development majors in a specific Field. In addition to basic preparation in that Field, he may minor in the Field of International Agricultural Development. The student may take courses which help him in applying his knowledge to the special conditions of newly developing nations, consult with experienced faculty members in regard to such application, and pursue a research project for his dissertation which is relevant to the special problems of newly developing countries. In much of this work the program in agriculture draws upon the strong international programs in other colleges of the University, including the area study programs and the varied offerings in modern languages.

Faculty experience in overseas work is continuously developed through work in College overseas programs and individual consulting assignments. Several faculty members, who devote themselves full time

to research and teaching in international agricultural development, have built special programs of research and continuing contact with particular geographic areas. The environment for the International Agricultural Development Program is further enhanced by more than 250 foreign graduate students majoring in the various fields of studies represented by the College of Agriculture.

Substantial expansion has recently taken place in the international program of several departments. Most departments have a number of assistantships and teaching fellowships designed to finance graduate students while they work closely with the teaching and research program in international agricultural development. Doctoral candidates in these departments, who are interested in international agricultural development, generally do field research in newly developing countries for their doctoral dissertations.

Additional information may be obtained by writing to Professor K. L. Turk, Director, International Agricultural Development Program, 102 Roberts Hall.

## International Legal Studies

The Cornell Law School offers a program of concentrated study in international legal subjects. The full program is ordinarily pursued by J.D. candidates in their second and third years of regular law study, but all the courses in the field are open to graduate students in law. Some of the courses are offered by visiting faculty members who come to the Law School under its program for distinguished foreign professors. A number of foreign scholars and students also come to Cornell for research and study in the comparative and international law fields. Other activities of the International Legal Studies Program have included faculty seminars in comparative law, summer conferences in public international law, and a program of speakers and seminars open to students. In addition, the Law School sponsors a small number of fellowships for foreign students to pursue graduate work in law.

For more detailed information, see the current *Announcement of the Law School*, the current *Annual Report of the Center for International Studies*, and the current *Announcement of the Center for International Studies*. Further information may be obtained by writing to Professor Robert A. Anthony, Chairman, Graduate Study Committee, the Cornell Law School, or to the Director, Center for International Studies, 217 Rand Hall.

## Latin American Program

FACULTY: Donald K. Freebairn, Director; Charles Ackerman, Frederick B. Agard, Solon Barraclough, Jerome S. Bernstein, Dalai Brenes, Frank Cancian, Tom E. Davis, Martin Dominguez, Matthew Drosdoff, Charles L. Eastlack, Rose K. Goldsen, Richard Graham, Eldon Kenworthy, Henry A. Landsberger, Thomas F. Lynch, Robert E. McDowell, James O. Morris, Thomas Poleman, Bernard Rosen, Donald F. Solá,

J. Mayone Stycos, Terence S. Turner, William W. Whyte, Frank W. Young.

The Latin American Studies Program enables the graduate student to develop specialized competence in the history, culture, social organization, and language of Latin American countries. The student majoring in a relevant discipline can minor in Latin American Studies.

Forty courses directly pertaining to Latin America are offered by the Departments of Agricultural Economics, Agronomy, Animal Science, Anthropology, Economics, Government, History, Housing and Design, Industrial and Labor Relations, Romance Studies, Rural Sociology, and Sociology. The courses constitute the basis for formulating programs leading to a graduate *minor* in Latin American Studies. Normally, five or six semester-long offerings satisfy the formal course requirements. In addition, the degree candidate minoring in Latin American Studies must exhibit proficiency in reading and speaking either Spanish or Portuguese.

Applications for scholarships, fellowships, or teaching fellowships should be made to the department in which the student is taking his major. Ford Foundation support for the Program enables the University to award approximately ten fellowships annually, each providing an academic-year stipend of \$2,250 to supplement an award of tuition and fees. The holders of the fellowships are designated Ford Foundation Fellows in Latin American Studies. Students minoring in Latin American Studies also qualify for Title VI N.D.E.A. Modern Language Fellowships. Application forms may be obtained from the Graduate School.

Summer research travel grants and support for on-campus course work during the summer are available to selected graduate students through the Latin American Studies Program. Although thesis research may be supported by the Program, support should first be sought from the Foreign Area Training Fellowship Program, the Social Science Research Council, Fulbright-Hays, the Doherty Foundation, and the Organization of American States.

Because of the considerable volume of research on Latin America currently being carried out by Cornell faculty members, students will normally be afforded the opportunity of participating in ongoing projects while in residence and will generally be expected to do field work in Latin America at some stage of their graduate training. Major research projects are under way in the fields of Andean community development, comparative economic development, fertility and population, descriptive linguistics, and urbanization.

Additional information may be obtained by writing to Donald K. Freebairn, Director, Latin American Program, Rand Hall.

## Near Eastern Studies

ADVISORY FACULTY COMMITTEE ON NEAR EASTERN STUDY: Isaac Rabinowitz, Chairman; A. Henry Detweiler, Alfred E. Kahn.

Students wishing to relate the work of their major or minor subjects to Near Eastern area or language studies should seek advice or information from the Faculty Committee on Near Eastern Studies. In a number of Fields, the University's resources for specialized graduate study and research on countries of the Near East are of considerable value. Members of the Committee can provide suggestions regarding relevant courses in various subjects, assistance in planning research on the Near East, and guidance in applying for area training or research fellowships. Inquiries should be addressed to Professor Isaac Rabinowitz, Chairman, Department of Semitic Languages and Literatures, 173 Goldwin Smith Hall.

## South Asia Program

(Bhutan, Ceylon, India, Nepal, Pakistan, Sikkim)

STAFF: Gerald Kelley, Director; Messrs. Douglas E. Ashford, Harold R. Capener, Arch T. Dotson, Gordon H. Fairbanks, Harold Feldman, James Gair, Leighton W. Hazlehurst, Michael Hugo-Brunt, Kenneth A. R. Kennedy, John W. Mellor, Stanley J. O'Connor, Morris E. Opler. The increasing importance of the peoples of the Indian subcontinent and of the role they play in world affairs enhances the need for providing opportunities in America for training and research in the field of Indic studies. The South Asia Program at Cornell, dealing primarily with India, Pakistan, Ceylon, and Nepal, is organized and equipped to help meet this need. Since 1948 it has sponsored a series of research projects on India and Ceylon, and it has trained a distinguished group of younger American and South Asian scholars in South Asian area and language studies. The Program faculty includes members from agricultural economics, anthropology, government, history of art, child development and family relationships, business and public administration, rural sociology, city and regional planning, and languages and linguistics. Sanskrit, Pali, Hindi, Urdu, Telugu, and Sinhalese are languages regularly offered at Cornell. Cornell participates in the interuniversity summer program which provides instruction in other South Asian languages and selected social sciences and humanities disciplines each summer on the campus of a member eastern university.

Qualified graduate students interested in specializing in the study of South Asia minor in Asian Studies with concentration on South Asia, in South Asian art history, or in South Asian linguistics. Advanced degree requirements for this minor are roughly comparable in terms given below. The doctoral candidate must have a reading knowledge of Hindi or, depending upon the subarea of his specialization, some other important language of South Asia.

## RESEARCH AND FIELD TRAINING

The doctoral dissertations of students in the South Asia Program are normally based on research done in India, Pakistan, Ceylon, or Nepal. Students' field research may benefit from advice and guidance in the



field by a program staff member. At least one member of the faculty of the South Asia Program has been in South Asia for each of the last several years. Cornell is a charter member of the American Institute of Indian Studies, which was organized to facilitate study and research in India by American advanced students and by faculty specializing in various aspects of Indian civilization and contemporary affairs. The University also maintains close links with a number of research agencies, programs, and institutions of higher learning, such as the Deccan College Postgraduate Research Centre, Delhi University, Osmania University (Hyderabad), and universities in Ceylon. Staff members of these institutions have provided valuable assistance to Cornell students working in India. There are opportunities for graduate students to become associated with Cornell-sponsored research in South Asia or to carry on independent research abroad. Every effort is made by the Program staff to aid qualified students to obtain financial support for a field training or research project in one of the countries of the area.

Research interests under the South Asia Program are focused largely on recent or contemporary developmental problems of the countries of the area—on changes taking place in the economic, political, social, religious, artistic, and intellectual life of the region. A long-term research project in progress in India is primarily concerned with the ramifying problems of introducing technological changes and the influence of such changes when adopted. For this research program, faculty and students in anthropology have carried on, since 1949, an extended and varied series of rural and urban community studies in several different regions of India from the Deccan into the Himalayan foothills. A major related project, the Cornell International Agricultural Development Program, which is supported by Ford Foundation funds, is concerned with the development of the entire agricultural sector of the Indian economy. With Ford Foundation support, Cornell is assisting Delhi University to become a major center in the field of linguistics. At the same time, other studies in urban renewal and regional planning, public administration, the role of government in cultural change, and recent movements in the arts and in religions and ideologies are in progress under faculty direction. Cornell is also making a special study of the Sinhalese language and of linguistic problems of Ceylon, a nation so far much neglected by American scholars. Research is also under way on Oriya and Telugu, important regional languages of India. The new nations of South Asia present so many problems for study that the areas of inquiry open to students and staff members are limited only by availability of research means.

## FELLOWSHIPS AND ASSISTANTSHIPS

Fellowship and assistantship awards are available to qualified graduate students minoring in Asian Studies with a concentration on South Asia. The South Asia Program fellowships are open to incoming graduate students with South Asia interests, and should be applied for by writing to the Director, South Asia Program, 221 Morrill Hall. These

fellowships are normally given to provide supplementary support for student research projects, at Cornell or in the field. Students in the South Asia Program are also eligible for assistantships in their major discipline departments, for fellowships and scholarships offered by the Cornell Graduate School, for National Defense Foreign Language Fellowships, and for Foreign Area Training Fellowships. Additional information on financial aid may be obtained by writing to the Director, at the address given above.

## Southeast Asia Program

**FACULTY:** John M. Allison, Benedict R. Anderson, Arch T. Dotson, John M. Echols, Frank H. Golay, Alexander B. Griswold, D. G. E. Hall, Robert B. Jones, Jr., George McT. Kahin, Stanley J. O'Connor, Robert A. Polson, Robert M. Quinn, Lauriston Sharp, James T. Siegel, John U. Wolff, O. W. Wolters.

The Southeast Asia Program possesses substantial facilities for study and research on the graduate level and provides exceptional opportunities for general or specialized work on all of Southeast Asia in various disciplines of the humanities, social sciences, and some natural sciences, as well as in interdisciplinary area seminars. Instruction in the major languages of the area is an integral part of the graduate training of the Southeast Asia Program. Much basic and pioneering research remains to be done in this area, and the Southeast Asia Program is organized and equipped to help meet such needs.

Special intensive instruction in Southeast Asian languages is available during summer sessions. Entering graduate students intending to study one of these languages are encouraged to begin such study during the summer preceding registration in the Graduate School. Inquiries should be made as early as possible to the Director of the Southeast Asia Program.

Southeast Asia Program Fellowships are available on a competitive basis to graduate students. They carry stipends of up to \$3,200 plus tuition and General Fee, and are available only to qualified candidates for advanced degrees at Cornell. Competition for these awards is open to citizens of the United States or Canada, nationals of Southeast Asian countries, and, in exceptional cases, nationals of other countries.

The fellowships are available to applicants who are able to demonstrate a serious scholarly interest in Southeast Asian studies; who show the greatest promise of becoming qualified regional experts with specialization in a relevant discipline of the humanities, social sciences, or certain natural sciences; and who are admitted to the Cornell Graduate School for advanced work in such a discipline. Previous experience in Southeast Asia or in the study of that area is not necessarily required. It is important that the applicant be able to show that advanced work in a major subject offered at Cornell, combined with work in the Southeast Asia Program, will make his future professional activities more effective; this requirement is particularly important for a student in the natural sciences.

Fellowships are normally awarded for one academic year. If the student's work during the first year has been of high caliber, reappointment is sometimes possible. In such cases, formal reapplication is expected from the student. The primary purpose of these awards is to encourage graduate students to acquire a substantial knowledge of Southeast Asia while majoring in one of the discipline fields of the Graduate School. Accordingly, they are usually offered only to students who take a minor in Asian Studies and participate fully in the Southeast Asia Program. The recipient of a fellowship may be asked to devote up to six hours a week under faculty supervision to work connected with the Program.

London-Cornell Studentships are available for advanced Ph.D. candidates in the social sciences and the humanities who have already had at least one year of resident study in the Southeast Asia Program. These fellowships are tenable for study during an academic year at the School of Economics and Political Science or the School of Oriental and African Studies in the University of London. Stipends range up to \$3,000 plus air fares and tuition and fees. London-Cornell Field Research Grants are open to Southeast Asia Program Ph.D. candidates in the social sciences and humanities after they have had appropriate training at Cornell, or at Cornell and London. They are tenable for up to twenty-two months for the purpose of dissertation research. Recipients of London-Cornell Field Research Grants may conduct research in any part of Southeast Asia. Stipends range up to \$12,000 for twenty-two months including travel and research expenses.

Cornell-Philippines Field Research Fellowships are available, under a grant from the Rockefeller Foundation, for advanced graduate students who plan to write dissertations in the social sciences or the humanities, based upon field research in the Philippines. Fellowship support is for ten to fifteen months in the Philippines and includes living costs, local transport, and roundtrip transportation from the United States for the graduate student and dependent wife or husband.

National Defense Foreign Language Fellowships, Title VI, are offered by the United States Office of Education for study during the academic year, the summer, or both. Application should be made to Sage Graduate Center, Cornell University. Information about Foreign Area Training Fellowships, administered by the Social Science Research Council, may be obtained by writing to the Foreign Area Fellowships Program, 444 Madison Avenue, New York, New York 10022. Graduate students may also apply for other fellowships, teaching fellowships, assistantships, and scholarships offered by the University and its departments.

Additional information on the Program and the various fellowships and awards may be obtained by writing to the Director, Southeast Asia Program, 108 Franklin Hall.

## Soviet Studies

COMMITTEE ON SOVIET STUDIES: George Gibian, Chairman; Urie Bronfenbrenner, M. Gardner Clark, Jack Fisher, Walter Galenson, Richard Leed, Walter Pintner, Myron Rush, George Staller.

**OTHER FACULTY MEMBERS IN SOVIET STUDIES:** Patricia Carden, Frederick Foos, Antonia Glasse, Boris Glasse, Martin Horwitz, Augusta Jaryc, Alla Novosilzova, Hugh Olmsted, Nicholas Troizkij, Marla Wykoff.

The University offers a number of courses and seminar on the Soviet Union as well as pre-1917 Russia. Instead of a separate area program, graduate students have a choice of majors and minors in the established Fields of the Graduate School. Some of the subjects focus on area specialization: Russian history, Russian literature, Slavic linguistics. Other subjects combine area specialization with a nonarea framework: comparative government, economic planning, regional planning, social psychology.

Graduate students pursuing Soviet Studies in any of these subjects are expected to attain proficiency in the Russian language either before entering the Graduate School or soon thereafter.

The University's academic activities related to Russia are coordinated by the Committee on Soviet Studies. The Committee also sponsors a colloquium for faculty members and graduate students in Soviet Studies. In the Soviet Studies Graduate Study in the John M. Olin Library, major reference works and key current periodicals from and about the U.S.S.R. are brought together.

The Committee on Soviet Studies selects a limited number of graduate students each year as research assistants. The Russian section of the Division of Modern Languages and the Department of Russian Literature also appoint several graduate students annually as teaching fellows in the Russian language. For other teaching fellowships, fellowships and scholarships, students apply directly to the Graduate School or to the department concerned. N.D.E.A. Title IV and Title VI fellowships are available in various subjects.

## FACULTY SPECIALIZATIONS

**ECONOMICS:** M. Gardner Clark, Walter Galenson, George J. Staller.

**HISTORY:** Walter M. Pintner.

**LANGUAGES AND LINGUISTICS:** Frederick Foos, Boris Glasse, Richard Leed, Mrs. Augusta Jaryc, Alla Novosilzova, Hugh Olmsted, Marla Wykoff.

**LITERATURE:** Miss Patricia Carden, George Gibian, Miss Antonia Glasse, Martin Horwitz, Hugh Olmsted.

**POLITICAL SCIENCE:** Myron Rush.

**PSYCHOLOGY:** Urie Bronfenbrenner.

**REGIONAL AND CITY PLANNING:** Jack C. Fisher.

Inquiries about fellowships and other aspects of Soviet Studies should be addressed to Professor George Gibian, Chairman, Committee on Soviet Studies, Goldwin Smith Hall.

## OTHER PROGRAMS AND CENTERS

### American Studies

COMMITTEE ON AMERICAN STUDIES: David B. Davis, Chairman; Archie R. Ammons, LeGrace G. Benson, Walter F. Berns, Jonathan P. Bishop, Stuart M. Brown, Jr., Douglas F. Dowd, Robert H. Elias, Robert T. Farrell, Heywood Fleisig, Paul W. Gates, Rose K. Goldsen, Andrew Hacker, Baxter L. Hathaway, Richard I. Hofferbert, Michael G. Kammen, Michael Kaufman, Walter LaFeber, Thomas W. Leavitt, John E. Martin, James H. Matlack, Dan E. McCall, James R. McConkey, Andrew J. Milnor, Arthur M. Mizener, Richard Polenber, Albert S. Roe, Clinton Rossiter, Joel H. Silbey, Allan P. Sindler, Walter J. Slatoff, James M. Smith, Fred Somkin, Gordon F. Streib, S. Cushing Strout, Robin M. Williams, Jr.

Although there is no formal program leading to a degree in American Studies, candidates for the doctorate in English and history will find ample opportunity to do interdisciplinary work in conjunction with a major in American Studies within their field. There are members of the staff in both fields who are professionally trained and currently active in the study of the interrelationships of American intellectual, literary, and social history, so that a student concentrating in American literature or American history may take advantage of the freedom permitted by Graduate School regulations and, in collaboration with his special committee, readily build an individual doctoral program that systematically embraces more than a single discipline. Inquiries concerning opportunities in this area should be addressed to Professor David B. Davis, Chairman, American Studies Committee, West Sibley Hall.

### Brookhaven National Laboratory

Cornell is one of nine eastern universities participating in Associated Universities, Inc. (AUI). Operating under contract with the Atomic Energy Commission, this corporation has the responsibility for the management of Brookhaven National Laboratory. The laboratory provides unusual research facilities for studies in biology, chemistry, applied mathematics, medicine, physics, high-energy particle physics, and reactor and nuclear engineering.

Graduate students may participate in research at Brookhaven by association with Cornell staff members who are engaged in research at the laboratory. Members of a variety of science departments at Cornell are currently involved in programs at Brookhaven. The laboratory also offers temporary summer appointments to a limited number of selected graduate and undergraduate students in science or engineering.

## Center for Environmental Quality Management

The Center for Environmental Quality Management brings together the faculties of the Cornell Medical College in New York and the various colleges and schools in Ithaca to study the manifold questions of environmental health in both urban and rural settings.

Current approaches to the modification and control of the environment, in concentrating on limited objectives such as air quality control, disease control, water quality control, pest control, food sanitation, occupational health, etc., have had limited success since they have been unable to take into account the interdependence of environmental health problems. The character and the urgency of the total environmental quality problem facing us appears insoluble short of an overall approach that will enable decision makers to consider simultaneously the significant variables and relationships relevant to the management of environmental quality.

Scientific management through systems analysis has begun to make it possible to consider these multiple relationships within the framework of common objectives and subject to predetermined constraints. It provides mechanisms by which various innovations can be examined in terms of their short and long-term effects upon the environment. Such an approach provides rational bases for establishing environmental quality goals and for the allocation of scarce resources to achieve these goals.

The Center is frequently able to provide predoctoral and postdoctoral fellowships for students interested in pursuing research topics in environmental health. For information regarding specific programs, write to Professor Walter R. Lynn, Director, Center for Environmental Quality Management, 302 Hollister Hall.

## Center for Housing and Environmental Studies

The purposes of the Center for Housing and Environmental Studies are to aid and guide basic research in the field of man's shelter and environment, to facilitate graduate study, and to aid the flow of information among colleges and departments and between the University and sources of information off campus. A small central staff assists in the initiation and conduct of projects.

The facilities of the Center for Housing and Environmental Studies are available to faculty members and graduate students in all Fields. Through the Center, students who cut across traditional lines of research may draw upon the knowledge and experience of specialists in such various subject areas as design, materials, equipment, structural methods, environment, family living, economics and finance, government, and health. The Director of the Center is Professor Glenn H. Beyer, West Sibley Hall.

The Division of Urban Studies of the Center has a broad range of research projects, with concentration in the areas of regional development, planning and heuristic gaming; and also has several publication

series. The Division is under the direction of Professor Barclay G. Jones, Associate Director for Urban Studies.

## Center for Radiophysics and Space Research

The Center for Radiophysics and Space Research unites research and graduate education carried on by several academic departments in the space sciences. It furnishes administrative support and provides facilities for faculty members and graduate assistants who are engaged in space research activities, and it offers opportunity for graduate students to undertake thesis work leading to the degrees of Master of Science and Doctor of Philosophy. A student's major professor can be chosen from the following Fields in the Graduate School: Aerospace Engineering, Applied Physics, Astronomy and Space Sciences, Chemistry, Electrical Engineering, Physics.

Thesis research in the following areas is now possible:

(a) Astronomy and Astrophysics. Astronomical aspects of cosmic rays, gamma-radiation, x rays, neutrinos; cosmology; experimental studies and theory relating to the surface of the moon and the planets; processes in the interstellar gas; solar-system magnetohydrodynamics; stellar statistics; theory of stellar structure, stellar evolution, nuclear processes in stars.

(b) Atmospheric and Ionospheric Radio Investigations. Dynamics of the atmosphere; incoherent electron scattering; study of refraction, scattering, attenuation due to the inhomogeneous nature of the troposphere and ionosphere; theory and observation of propagation of radio waves in ionized media such as the ionosphere.

(c) Radar and Radio Astronomy. Distribution and classification of radio sources; radar investigations of the moon and planets; solar radio observations; studies of gaseous nebulae.

(d) Space Vehicle Instrumentation. Instrumentation relating to lunar exploration; magnetic field measurements; tenuous gas and particle flux measurements; infrared observations from rockets.

The facilities of the Center include the lunar surface and electronics laboratory on the Cornell campus, the radio astronomy and ionospheric laboratories close to Ithaca, and the Arecibo Ionospheric Observatory in Puerto Rico. At Arecibo an extremely sensitive radio telescope and an unusually powerful space radar are available for use by qualified graduate students. In addition, certain facilities of Sydney University, Australia, are available through the Cornell-Sydney University Astronomy Center (see below).

## Center for Research in Education

The Center for Research in Education provides an institutional focus within the University for the interests of faculty members from different disciplines in educational research and development. In addition, the

Center attempts to stimulate investigation of socially significant educational problems and to train students in educational research. At present, research projects in adult-child interaction and cognitive socialization, in language development and literacy, in science education, and in early school learning are under way. Research programs in mathematics education and in undergraduate education are being planned.

The Center provides predoctoral and postdoctoral training through research assistantships, training grants, and postdoctoral fellowships. For information write to Professor Alfred L. Baldwin, Director, Center for Research in Education, Rand Hall.

## Cornell-Sydney University Astronomy Center

The Center is an inter-University organization designed to create a larger pool of facilities and skills for research in astronomy and related fields than would be separately available to either university. Graduate students can be interchanged between the two institutions whenever appropriate for the research work in which they are engaged. Both universities recognize research supervision extended by the sister university, and the time spent by a student on thesis work in the sister university can be accepted toward residence requirements with the proviso that the approval of the home research supervisor is given and also that the home university bylaws are not contravened.

The facilities available through the Center, in addition to those of Cornell's Center for Radiophysics and Space Research, are the one-mile by one-mile Mills Cross situated at Hoskinstown, New South Wales; the stellar intensity interferometer situated at Narrabri, New South Wales; the Criss-Cross, the Shain Cross, and Mills Cross situated at Fleurs, New South Wales; the Wills Plasma Physics Department, the Basser Computing Department, the Falkner Nuclear Department, and the facilities of the cosmic ray group at the University of Sydney. The Center includes H. Messel, R. Hanbury Brown, W. N. Christiansen, C. B. A. McCusker, and B. Y. Mills from the University of Sydney faculty.

Further information can be obtained from Professor T. Gold, Joint Director, Cornell-Sydney University Astronomy Center, Space Science Building, Cornell University.

## Developmental Studies

Specialization in this area normally involves participation in a program jointly sponsored by the Fields of Child Development and Family Relationships, and Psychology. The program presently emphasizes cognitive development. Students interested in the program should apply to either the Field of Child Development and Family Relationships, or Psychology. Training in research skills in both Fields is recommended. Students admitted to the program fulfill the requirements of whichever Field they enter. Current research interests of the faculty



include development of language, perception, thinking, intellectual development in natural settings, conceptual and affective behavior in infancy, cognitive socialization, and biological maturation. For further information see the description of the Fields of Psychology, and Child Development and Family Relationships, or write to either Field Representative.

## Division of Biological Sciences

The Division of Biological Sciences was established in 1964 to bring together into a single administrative unit a number of investigators and teachers representing a broad spectrum of interests in basic biology. Its members hold appointments in one or more of four schools and colleges but serve the University as a whole through the Division. The Division is responsible for all the undergraduate teaching of biology, including the establishment of requirements for the major in its various branches. It also has the primary responsibility for the promotion of research in basic biology, and its members engage in graduate teaching through participation in appropriate Fields in the Graduate School Faculty. At present the following subject areas are represented by separate sections of the Division: biochemistry and molecular biology; ecology and systematics; genetics, development, and physiology; microbiology; and neurobiology and behavior. A number of graduate fellowships, teaching fellowships, research assistantships, and traineeships are available through the Division. For further information, contact Dr. Robert Morison, 201 Roberts Hall.

## Materials Science Center

The Materials Science Center (MSC) at Cornell is an interdisciplinary laboratory created to promote research and graduate student training in all phases of the science of materials. The subjects of study represented in the MSC program are applied physics, chemistry, electrical engineering, materials engineering, materials science, mechanics, metallurgy, and physics.

The extent of the benefits a graduate student may derive from the MSC program depends on the actual research he pursues. If the student chooses to follow the more conventional course of becoming a specialist in one specific area, the MSC program could help him by providing new equipment, financial assistance through research assistantships, or, in some cases, the help of a technician to carry out routine measurements.

If the student wishes to follow a program of considerably more breadth than usual in his research training, the MSC program provides an additional advantage. Several central facilities have been set up where more specialized apparatus such as crystal-growing furnaces, high-pressure equipment, x-ray and metallography equipment, electron microscopes, etc., are available to all MSC members and their students.

In addition to the equipment, expert advice on its use and the interpretation of the results will be available. In these central facilities, it is expected that the student will come in contact with students from other disciplines, resulting in a mutually profitable interaction.

The office of the Director of the Materials Science Center, Professor R. E. Hughes, is in Room 627, Clark Hall.

## Military Science, Naval Science, and Aerospace Studies

(ROTC, NROTC, and AFROTC)

The advanced course in military science (Army ROTC), naval science (Naval ROTC), and aerospace studies (Air Force ROTC) is open to graduate students who have satisfactorily completed a basic course in ROTC or who enroll in a two-year ROTC program. Successful completion of the two-year advanced ROTC course will qualify a graduate student for appointment as a Second Lieutenant in the U.S. Army, Air Force, or Marine Corps Reserve; or Ensign, U. S. Naval Reserve; or as Second Lieutenant in the Regular Army or Air Force. Interested graduate students should consult the *Announcement of Officer Education* and apply to the Professor of Military Science, the Professor of Naval Science, or the Professor of Aerospace Studies (ROTC), Barton Hall.

## Statistics Center

The methods of statistics find important applications in many diverse fields of research. It is therefore necessary that (1) subject matter specialists be able to obtain assistance in using or developing statistical theory, (2) students who intend to do research work in a particular field which makes extensive use of statistical methods receive adequate training in statistics, and (3) individuals be trained as statisticians.

The staff members of the various schools and colleges of Cornell University who are interested in the development and application of statistical methods are associated with the Cornell Statistics Center. A major responsibility of the Center is to provide a focal point to which individuals, projects, and departments may come to receive assistance and guidance with respect to the statistical aspects of research and training programs.

The Acting Director of the Center is Professor Philip J. McCarthy, Ives Hall.

## Center for Water Resources and Marine Sciences

The Center is an interdisciplinary organization serving the entire University at the graduate study and research level. Its purpose is to pro-

mote and coordinate a comprehensive program in water resources planning, development, and management in such areas as the sciences, engineering, agriculture, law, economics, government, regional planning, and public health.

Its responsibilities are to undertake water resources research in engineering, in the physical, biological, and social sciences, and in the humanities; to encourage and contribute to graduate studies in water resources; to coordinate research and training activities in water resources; to encourage new combinations of disciplines in research and training which can be brought to bear on water resource problems; to disseminate the results of research; and to develop and operate central facilities which may be needed to serve participants in research and training.

Correspondence concerning the Center should be directed to Professor L. B. Dworsky, Director, Center for Water Resources and Marine Sciences, Hollister Hall.

Correspondence related to graduate study in the Field of Water Resources should be directed to the Field Representative, Professor C. D. Gates, Hollister Hall.

## SPECIAL FACILITIES AND SERVICE ORGANIZATIONS

### New York State Agricultural Experiment Station at Geneva

The New York State Agricultural Experiment Station was established in 1880 to promote agriculture through scientific investigations and experimentation. It is located at Geneva, fifty miles from Ithaca, and has been under the administration of Cornell University since 1923.

Professors on the Geneva staff are eligible to serve as members of the Special Committees of graduate students along with professors on the Ithaca campus of the University. Normally the graduate training provided at Geneva consists of research experience and supervision of the student's work on a thesis problem. The formal course work part of the student's training program is given on the Ithaca campus. Students who plan to do part of their graduate work at Geneva should correspond with their major advisers or with the Dean of the Graduate School concerning regulations as to residence, Special Committees, etc.

The Station is equipped to care for graduate students in certain specific lines of research, viz., chemistry, economic entomology, food technology, microbiology, plant pathology, pomology, seed investigations, and vegetable crops. Ample facilities are available for graduate research under laboratory, greenhouse, pilot plant, insectary, orchard, and other field conditions.

Certain phases of the investigations now being conducted at the Station and other problems for which the facilities of the Station are suitable may be used as thesis problems by graduate students.

The Director is Professor D. W. Barton, who may be addressed at the New York State Agricultural Experiment Station, Geneva, N.Y. 14456.

## Office of Computer Services

The principal computing facility at Cornell is an IBM 360 Model 65 located at Langmuir Laboratory at the Cornell Research Park. The system is equipped for remote access of several kinds, and the operating system is designed so that very few users find it necessary to visit Langmuir. The primary terminals are high-speed reader-printers located in Upson, Clark, and Warren Halls. While these are remote job-entry and delivery devices rather than conversational terminals, they permit convenient access, job turnaround-time in terms of minutes, and the use of on-line files. Each of these terminals is the core of a small computing center, with auxiliary equipment, consulting assistance, reference material, and work space. In addition to these high-speed terminals, teletypewriter terminals are available to individual projects that require interactive capability.

Two IBM 1800 computers that control various real-time laboratory devices are also linked directly to the 360/65. These machines provide graphical input-output capability and an analog-digital interface.

This computing system is busy but not saturated, and use by graduate students is encouraged.

The Office of Computer Services is responsible for the operation of this system and for the provision of consulting and programming assistance. The Office cooperates with the Department of Computer Science in providing courses in programming and computing techniques. Both organizations employ a number of graduate students on assistantships and part-time appointments for this work.

For further information write to the Office of Computer Services, Langmuir Laboratory.

## University Press

Cornell University Press, founded by Andrew D. White in 1869, was the first university press in America and is among the leaders in number of volumes published annually. The Press publishes scholarly books on nearly every academic subject, serious nonfiction of general interest, and advanced or experimental textbooks for universities. The imprint of Comstock Publishing Associates, a division of the Press, is placed on certain books in the biological sciences. The Press also publishes a paperbound series, Cornell Paperbacks. More than 20 per cent of the books published by the Press in recent years were written by members of the Cornell University faculty. All printing for the Press is done under contract by various book manufacturing firms; the Press has no production facilities of its own.

## Visual Aids

The University owns and operates the Photo Science Studios, which create or cooperate in the creation of photographic studies and visual aids of all kinds.

The extension services of the New York State Colleges, which form integral parts of the University, disseminate knowledge through an intensive program of publication, photography, and recording supervised by professional staffs. Materials produced by graduate students may find outlets through these channels.

## Other Research Units

Some other research units allied with the University, either as wholly owned and operated divisions or as wholly or partially autonomous organizations with which the University has a working agreement, are the Sloan-Kettering Cancer Research Institute in New York City, through the Graduate School of Medical Sciences, and the Veterinary Virus Research Institute in Ithaca.

Cornell is also one of fourteen founding members of the University Corporation for Atmospheric Research which, under National Science Foundation support, operates the National Center for Atmospheric Research at Boulder, Colorado. In addition to Brookhaven National Laboratory, Cornell, as a member of Associated Universities, Inc., has access to the facilities of the National Radio Astronomy Observatory in Greenbank, West Virginia.

Further opportunities for formal study, field work, and independent research by Cornell graduate students are available in many institutions, laboratories, and libraries both in the United States and in other countries. For example, the Cornell-Harvard Archaeological Exploration at Sardis, Turkey, and the Museum of Northern Arizona at Flagstaff, Arizona, both provide opportunities for field research related to doctoral work of Cornell graduate students. Information on that kind of arrangement is available directly from the Field Representatives.

## GRADUATE SCHOOL OF MEDICAL SCIENCES

The opportunity for graduate work leading to advanced general degrees was first offered in the Medical College in 1912 in cooperation with the Graduate School of Cornell University. In June 1950, the trustees of Cornell University entered into an agreement with the Sloan-Kettering Institute for Cancer Research whereby a new division of the Medical College, namely, the Sloan-Kettering Division, was created for the purpose of offering additional opportunities for graduate study toward advanced degrees, thus extending the areas of the basic sciences.

That expansion of the New York City component of the Graduate School resulted in the establishment in January 1952, of the Graduate School of Medical Sciences which, with the approval of the faculty of

the Graduate School of Cornell University, was given the full responsibility for administrative matters related to the advanced general degrees granted for study in residence at the New York City campus of Cornell University.

**DEGREES.** The general degrees of Ph.D. and M.S. are awarded for advanced study and scholarly, independent research in the fields of anatomy, biochemistry, biomathematics, biophysics, biostatistics, cell biology, genetics, microbiology, neurobiology and behavior, pharmacology, and physiology.

**FACILITIES.** The facilities for graduate work at the Graduate School of Medical Sciences include those of the Medical College and of the Sloan-Kettering Division. The five buildings of the Medical College, extending along York Avenue from 68th to 70th Street in New York City, contain the lecture rooms, student laboratories, library, and research facilities for graduate and undergraduate work. The Sloan-Kettering Division is located in the Sloan-Kettering Institute and the Kettering Laboratory on East 68th Street in New York City, and in the Walker Laboratory in Rye, New York. The special facilities and experienced investigators of the Sloan-Kettering Division offer ample opportunity for advanced graduate work in the basic science aspects of research related to cancer and allied diseases.

**FINANCIAL ASSISTANCE.** Predoctoral fellowships are available to qualified applicants. The fellowships may be renewed yearly providing the academic performance of the fellowship holders is satisfactory. Teaching fellowships and research assistantships are available to qualified graduate students in some departments of the Medical College. In addition to a stipend, the costs of tuition and fees are defrayed for those students receiving financial assistance.

**FURTHER INFORMATION.** Information on financial assistance and the entire program of the Graduate School of Medical Sciences is provided in the *Announcement of the Graduate School of Medical Sciences*. Requests for that Announcement should be addressed to the Graduate School of Medical Sciences, Cornell University Medical College, 1300 York Avenue, New York 10021.

# FIELDS OF INSTRUCTION

**REPRESENTATIVES.** Since instruction in the Graduate School is primarily individual, those interested in becoming students are encouraged to communicate with individual members of the faculty with whom they may want to study. Personal interviews in advance of formal application for admission are especially encouraged. For the benefit of those who are not acquainted with appropriate members in the Field or Fields of their interest, each Field has selected a representative, as director of graduate studies, to whom inquiries may be addressed.

## AEROSPACE ENGINEERING

**Faculty:** Peter L. Auer, P. C. Tobias de Boer, Albert R. George, Geoffrey S. S. Ludford, Edwin L. Resler, Jr., William R. Sears, A. Richard Seebass, Shan-fu Shen, Donald L. Turcotte.

**Field Representative:** Donald L. Turcotte, 289 Grumman Hall.

### MAJOR SUBJECT

Aerospace Engineering

### MINOR SUBJECTS

Aerospace Engineering

Aerodynamics

The requirement for admission in this Field is a Bachelor's degree in engineering or the physical sciences. It is not recommended that candidates apply for admission at midyear, except in unusual cases.

The language requirement for the Ph.D. is one language in addition to the candidate's native language: either French, German, or Russian at the level of the ETS Language Examination, or English.

There is no final comprehensive examination required for the Master's degree. Ph.D. candidates must take both the Admission to Candidacy and Final Thesis Examinations required by the Graduate School. A description of these is found on page 12 of this *Announcement*.

In this Field of graduate study emphasis is placed on the aerospace sciences rather than proficiency in present-day techniques. Consequently, graduate students having aerospace engineering as their major subject will be urged to select as their minor subjects the basic sciences, such as chemistry, mathematics, mechanics, and physics. There are several special fellowship awards supported by the Aeronautical Laboratory available to students in this Field.

Much of the research carried out in this Field at Cornell is concerned with fundamental problems in the dynamics of fluids, including plasmas and chemical reactions at high temperature. Whenever possible, these investigations combine the techniques of theory and laboratory experiment, making use of the experimental facilities of the Graduate School of Aerospace Engineering on the campus. In every investigation, an attempt is made to correlate theory with observation and practical experience.

A group working under the direction of Professors de Boer and Resler is investigating the dynamics of gases at extreme temperatures. Generally speaking, their interests lie in matters in which the sciences of physics and chemistry are finding application to the aerodynamics of propulsion systems and to flight of missiles and space vehicles.

The branch of fluid mechanics called magnetohydrodynamics now forms an essential part of the activities of the Graduate School of Aerospace Engi-

neering; Professors Resler, Sears, and Turcotte are engaged in this research, both in theory and in the laboratory. Professor Ludford of the Department of Theoretical and Applied Mechanics is exploring the mathematical theory of this phase of fluid mechanics. Professor Auer, Director of the Laboratory for Plasma Studies, is concerned with those aspects of plasma physics concerned with the higher temperature collisionless regime appropriate to possible fusion applications. This interest brings the School into close contact with several other departments of the University (including the Center for Applied Mathematics, the Laboratory for Plasma Studies, and the Center for Radiophysics and Space Research). Professors George, Seebass, and Shen and their students are pursuing investigations in the area of rarefied-gas dynamics, hypersonics, basic fluid mechanics, and advanced aerodynamics, which are related to the other aspects of real-gas dynamics and air chemistry mentioned above. The staff is also actively engaged in studies of the sonic boom and associated problems concerned with high performance aircraft. Close contact is maintained with the work in Thermal Engineering, which is housed in Upson Hall adjacent to this School. The School also maintains active interest and research in subjects basic to modern space vehicle and propulsion-system design, including problems of missile dynamics, trajectories, and orbits. Research in chemical kinetics is conducted with the cooperation of Professor S. H. Bauer of the Department of Chemistry, and research in structures and materials is carried out in cooperation with the Field of Theoretical and Applied Mechanics and the Materials Sciences Center. This brief description is, of course, not all-inclusive and other topics of research are under study. Further details may be obtained by writing to the Director of the Graduate School of Aerospace Engineering, Grumman Hall.

Candidates for an advanced degree with a major in this Field who do not already hold the Master's degree are encouraged to matriculate first as candidates for the professional degree, Master of Engineering (Aerospace), under the jurisdiction of the Graduate School of Aerospace Engineering. Information concerning this School and the degree of Master of Engineering (Aerospace) will be found in the *Announcement of the College of Engineering*.

## Courses

### 7101. ADVANCED KINETIC THEORY

Fall term. Credit three hours. Mr. de Boer.

The Boltzmann equation. Solution for gas in equilibrium. Collision frequency and mean free path calculations. Conservation equations. Review of Enskog-Chapman theory of transport coefficients. Grad's thirteen moment equations. The BGK equation. The BBGKY theory.

### 7102. GASDYNAMICS

Spring term. Credit three hours. Mr. Resler.

Strong shock waves and their use in the production and study of high temperature gases. High temperature chemical kinetics and its application to hypersonic external flows, rocket internal flows, and other phenomena of current interest. Chemical relaxation effects on flow fields and the method of characteristics including chemical reactions. Experimental techniques.

### 7103. DYNAMICS OF RAREFIED GASES

Spring term. Credit three hours. Prerequisites: 7101 and 7102. Mr. Shen.

Flow regimes according to the Knudsen number. Theories of the shock structure at high Mach numbers. Boundary conditions at a solid wall. Slip-



flow conditions. Free-molecule flows. Eigen function expansion of the linearized Boltzmann equation. Full-range and half-range moment methods. The model equation approach and recent developments for handling the transition regime.

#### 7104. ADVANCED TOPICS IN HIGH TEMPERATURE GASDYNAMICS

Either term. Credit three hours. Prerequisites: 7101 and 7102.

Current topics relating to present engineering practice and/or research interests of the faculty and staff.

#### 7201. INTRODUCTORY PLASMADYNAMICS

Fall term. Credit three hours. Mr. Auer.

Macroscopic and microscopic properties of plasmas. Wave motion and stability. Character of laboratory-produced and naturally occurring plasma systems. Application to power conversion and space propulsion. Introduction to controlled thermonuclear research.

#### 7202. INTRODUCTORY MAGNETOHYDRODYNAMICS

Spring term. Credit three hours. Mr. Turcotte.

Basic equations of magnetohydrodynamics. Flow problems. Hydromagnetic shock waves. The pinch effect and instabilities. Tensor conductivity and excess electron temperature.

#### 7203. INTERMEDIATE PLASMA PHYSICS

Spring term. Credit three hours. Prerequisite: 4561 or 7201 or equivalent. Mr. Auer.

Collective oscillations in a cold plasma; waves in a warm plasma; application to natural phenomena. Nonlinear theory of collision-free shocks. Quantum effects in solid state plasma waves; plasma-phonon interactions. Introduction to radiation and scattering in plasmas. At the level of Stix: *Theory of Plasma Waves*, and Bekefi: *Radiation Processes in Plasmas*.

#### 7301. FLUID MECHANICS

Fall term. Credit three hours. Mr. George.

The continuum and the stress tensor. Vectors and tensors. Hydrostatics. Strain and rate-of-strain tensors. Constitutive equations. The ideal elastic continuum. Equilibrium and compatibility equations, boundary conditions. Plane stress and strain. The stress function. Elastic energy. St. Venant's principle. The Newtonian fluid, viscosity and bulk viscosity Navier-Stokes equations. Poiseuille flow, Rayleigh and Stokes problems. The concept of the boundary layer. The ideal-fluid approximation. Kelvin and Helmholtz theorems. Irrotational flows.

#### 7302. AERODYNAMICS

Spring term. Credit three hours. Mr. Sears.

Laplace's equation. Source, sink, and doublet. Vortices. Biot-Savart theorem, the flow field of a vortex. Spherical and cylindrical harmonics. Methods of singularity distributions. Complex-variable methods. Wing theory. Acoustics. Compressible flows, subsonic and supersonic. Shock waves. Hypersonic flow. Rotational flows. Magnetohydrodynamics. Flow in the boundary layer, Prandtl theory. Heat transfer, separation.

#### 7303. COMPRESSIBLE FLUID FLOW

Spring term. Credit three hours. Mr. George or Mr. Seebass.

Aerodynamics of compressible fluids. Brief review of linear theories. Im-

provements on linear theory. Theory of sonic boom. Role of entropy in supersonic flows. Shock wave interactions. Exact theories: method of characteristics for rotational reacting flows; conical flows. Transonic flow theory and similitude. Viscous effects in compressible flows. Other topics of current interest.

#### 7304. THEORIES OF VISCOUS FLOWS

Fall term. Credit three hours. Prerequisites: 7301 and 7302. Mr. Shen.

Exact solutions of the Navier-Stokes equations. The small Reynolds number approximation. The boundary layer theory and the techniques for its solution. Compressibility effects. Stability of laminar flows. Turbulence.

#### 7305. HYPERSONIC FLOW THEORY

On demand. Credit three hours. Prerequisites: 7301 and 7302. Mr. George or Mr. Seebass.

Hypersonic small disturbance theory and the related similitude; blast wave analogy; entropy layers. Newtonian theory and shock layer structure. Constant density solutions. The blunt body problem; numerical techniques. Viscous and real gas effects: ideal dissociating gas; viscous interactions; other real gas phenomena.

#### 7801. RESEARCH IN AEROSPACE ENGINEERING

Throughout the year. Credit to be arranged. Prerequisite: admission to the Graduate School of Aerospace Engineering and approval of the Director.

Independent research in a field of aerospace science. Such research must be under the guidance of a member of the staff and must be of a scientific character.

#### 7901. AEROSPACE ENGINEERING COLLOQUIUM

Throughout the year. Credit one hour.

Lectures by Cornell staff members, graduate students, and visiting scientists on topics of interest in aerospace science, especially in connection with new research.

#### 7902. SEMINAR IN AEROSPACE ENGINEERING

Throughout the year. Credit two hours. Prerequisite: approval of the Director.

Study and discussion of topics of current research interest in aerospace engineering. Members of the seminar will prepare and deliver reports on these topics, based on published literature.

#### 7903. PLASMA PHYSICS COLLOQUIUM

Fall and spring terms. Credit one hour.

Lectures by staff members, graduate students, and outside scientists on topics of current interest in plasma research.

## AGRICULTURAL ENGINEERING

Faculty: Richard D. Black, J. Robert Cooke, Edward W. Foss, Orval C. French, Ronald B. Furry, Richard W. Guest, Wesley W. Gunkel, Fred G. Lechner, Gilbert Levine, Raymond C. Lochr, Robert T. Lorenzen, David C. Ludington, Everett D. Markwardt, William F. Millier, Gerald E. Rehkugler, Norman R. Scott, E. Stanley Shepardson, James W. Spencer, Clesson N. Turner.

Field Representative: Wesley W. Gunkel, 226 Riley-Robb Hall.

## MAJOR AND MINOR SUBJECTS

Agricultural Engineering

Agricultural Structures

Electric Power and Processing

Power and Machinery

Soil and Water Engineering

Ph.D. candidates are required to have one major subject selected from the above list and two minor subjects. One minor subject may be selected from the above list, and at least one minor subject must be selected in a Field outside Agricultural Engineering. M.S. candidates are required to take Agricultural Engineering as their major subject and to select one minor outside the Field. Candidates for either the doctorate or the Master's degree with the major outside the Field may select any subject as a minor.

**ADMISSION REQUIREMENTS.** To be considered for admission an applicant must have a baccalaureate degree in an area of engineering, physical science, or biological science from a faculty or university of recognized standing. Training in the engineering and biological sciences is necessary. Any deficiencies in these areas in the undergraduate training will need to be satisfied early in the advanced degree program. The applicant must present evidence of promise in advanced study and research as indicated by past scholastic achievement and recommendations from his undergraduate or graduate institution.

Although it is not required by the Field, applicants applying for fellowships and scholarships are strongly urged to take both the Graduate Record Examination Aptitude and the Advanced Engineering Tests given by the Educational Testing Service. Scores should be sent to the Cornell Graduate School as part of the application.

**LANGUAGE REQUIREMENTS FOR ADVANCED DEGREES.** There is no general language requirement for either the M.S. or the Ph.D. degree in the Field. However, a candidate's Special Committee may require language to be included in the student's program.

**EXAMINATIONS.** The final examination for the M.S. degree may be oral, or oral and written. Students continuing for the Ph.D. degree in the Field may, under unusual circumstances and with the permission of their Special Committee for the Ph.D. program, combine the M.S. final examination with the Admission to Candidacy Examination, which, together with the final examination on the thesis, is required of all Ph.D. candidates.

**RESEARCH AND STUDY OPPORTUNITIES.** A broad spectrum of research and study activity is available in Agricultural Engineering. A thesis based on research effort is required for both the M.S. and Ph.D. degrees. A partial list of the general areas of research interest and the faculty members associated with these interests are listed below. Specific topics of mutual interest may also be selected. If you desire information about current research projects, the Field Representative will direct your inquiry to the faculty member best able to answer your request.

**Agricultural Engineering:** All faculty members. Agricultural mechanization, agricultural waste management, bioengineering, engineering properties of biological materials, low-cost roads, materials handling, safety engineering.

**Agricultural Structures:** Ronald B. Furry, Robert T. Lorenzen, Norman R. Scott. Structural analysis and design, production systems synthesis, structural-biological relationships, environmental composition and control, biological response to environment, thermodynamic processes.

**Electric Power and Processing:** Ronald B. Furry, Richard W. Guest, David C. Ludington, E. Stanley Shepardson, Clesson N. Turner. Electrical control systems, processing of agricultural materials, application of electromagnetic radiation to agriculture.

**Power and Machinery:** J. Robert Cooke, Richard W. Guest, Wesley W. Gunkel, Everett D. Markwardt, William F. Millier, Gerald E. Rehkugler, E. Stanley Shepardson. Agricultural machinery design and development, terramechanics, crop harvesting, handling and processing systems, metering and distribution of agricultural chemicals, physical and biological factors pertaining to machine design such as soil mechanics in relation to seedling development.

**Soil and Water Engineering:** Richard D. Black and Gilbert Levine. Surface water hydrology, flow in porous media, irrigation efficiency, soil-plant-water relationships, waste water disposal, hydraulics.

## Professional Degree

The Department of Agricultural Engineering also offers the professional degree of Master of Engineering (Agricultural) which is intended primarily for those students who plan to enter engineering practice, and not for those who expect to study for the doctorate. This program consists of courses which are intended to develop the student's background in engineering design as well as strengthen his fundamental engineering base. Of the required thirty hours, six consist of engineering design experience involving individual effort and a formal report.

Admission to the Master of Engineering (Agricultural) program is open to persons who have been granted Bachelor's degrees, or the equivalent, and who have sufficient training to indicate that they can profitably study the advanced courses offered for these students in engineering. A student can choose to concentrate his studies in one of the sub-areas of Agricultural Engineering or take a broad program without specialization.

## Graduate Courses

### 501. SIMILITUDE ENGINEERING

Spring term. Credit three hours. Two lectures, one laboratory. Time and place to be arranged. Associate Professor Furry.

Similitude methodology, including the use of dimensional analysis to develop general equations to define physical phenomena; model theory; distorted models; and analogies, including the use of electronic and digital analog computers. Introduction to a variety of applications in engineering. It is preferred that students know how to program in FORTRAN, although knowledge of CUPL is acceptable.

### 502. INSTRUMENTATION

Spring term. Credit three hours. Two lectures, one laboratory. Time and place to be arranged. Assistant Professor Scott and staff.

Application of instrumentation to physical and biological measurements in agricultural and biological research; including measurement of force, displacement, velocity, acceleration, pressure flow of materials, electric and magnetic quantities, temperature, humidity, chemical composition analysis, particle

size, and electric magnetic radiation, with emphasis on transducers and recording methods.

#### 504. BIOLOGICAL ENGINEERING ANALYSIS

Fall term. Credit three hours. Three lectures. Riley-Robb 225. Time to be arranged. Prerequisite: consent of the instructor or Engineering 1151. Assistant Professor Cooke.

Engineering problem-solving techniques will be examined. Particular attention will be given to the formulation of biological problems in an engineering context. Experience will be gained in problem definition, mathematical formulation, and interpretation of results. Principles of feedback control theory will be studied and applied to biological and technological systems.

#### 551-552. AGRICULTURAL ENGINEERING PROJECT

Fall and spring term (both terms required for M.E. (Agr.) degree). Credit three hours per term. Time and place to be arranged. Staff.

Comprehensive design projects utilizing real engineering problems to present fundamentals of agricultural engineering design. Emphasis on formulation of alternate design proposals, including economics and nontechnical factors, and complete design of the best alternative.

#### 600. SPECIAL TOPICS

Fall or spring term. Credit one or more hours. Time and place to be arranged. Staff.

Special work in any area of agricultural engineering on problems of special interest to the students and faculty.

#### 601. GENERAL SEMINAR

Fall and spring terms. Fall term required of all graduate students majoring in the Field. Spring term optional. M 12:30. Riley-Robb 400. Staff.

Presentation and discussion of research and special developments in agricultural engineering and other fields.

#### 602. POWER AND MACHINERY SEMINAR

#### 603. SOILS AND WATER ENGINEERING SEMINAR

#### 604. AGRICULTURAL STRUCTURES SEMINAR

Spring term. Seminars 602, 603, 604: credit one hour each. Time and place to be arranged. Staff.

Thorough investigation and discussion of research or new developments in an area of special interest to those enrolled.

## Undergraduate Courses Open to Graduate Students

#### [461. AGRICULTURAL MACHINERY DESIGN]

Spring term. Credit three hours. Prerequisite: Engineering 3331 or the equivalent. Two lectures, one laboratory. Time and place to be arranged. Professor Gunkel. Offered in alternate years. Not offered in 1969-70.

The principles of design and development of agricultural machines to meet functional requirements. Emphasis is given to computer-aided analysis

and design, stress analysis, selection of construction materials, and testing procedures involved in agricultural machine development.

#### 462. AGRICULTURAL POWER

Fall term. Credit three hours. Prerequisite: Engineering 212 or the equivalent. Two lectures, one laboratory. Time and place to be arranged. Offered in alternate years.

Basic theory, analysis, and testing of internal combustion engines specifically for use in farm tractors and other agricultural power applications. Tractor transmissions. Nebraska Tractor Tests, soil mechanics related to traction, stability, shop dynamometers, fuels, hydraulic equipment.

#### [463. PROCESSING AND HANDLING SYSTEMS FOR AGRICULTURAL MATERIALS]

Spring term. Credit four hours. Three lectures, one laboratory. Time and place to be arranged. Associate Professor Furry. Offered in alternate years. Not offered in 1969-70.

Processes such as size reduction, separation, metering, drying, and refrigeration will be studied. Psychrometrics, fluid flow measurement, and an introduction to system engineering and electrical controls for agricultural applications is included. The student should know how to program in FORTRAN or CUPL.

#### 471. SOIL AND WATER ENGINEERING

Spring term. Credit three hours. Prerequisites: Engineering 2301 and Agronomy 200, or their equivalents. Three lectures, one laboratory every other week. Time and place to be arranged. Associate Professor Black. Offered in alternate years.

An advanced course in the application of engineering principles to the problems of soil and water control in agriculture. Includes design and construction of drainage systems and farm ponds, and design and operation of sprinkler systems for irrigation.

#### 481. AGRICULTURAL STRUCTURES

Spring term. Credit three hours. Prerequisites: Engineering 2701 and 3622, or equivalent. Lectures, T Th 11:15. Laboratory, W 2-4:25. Place to be arranged. Assistant Professor Scott. Offered in alternate years.

Synthesis of complete farmstead production units including structures, equipment, and management techniques. Integrated application of structural theory, thermodynamics, machine design, and methods engineering to satisfy biological and economic requirements.

#### 491. LOW-COST ROADS

Credit three hours. Primarily for application to developing countries. Offered upon sufficient demand, usually in fall term. Prerequisite: consent of the instructor. Principally directed study with one class session of two and a half hours per week to be arranged. Professor Spencer.

Study of economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics and classification; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

## APPLIED MATHEMATICS<sup>1</sup>

Faculty: Michael S. Balch, Louis J. Billera, Henry David Block, James H. Bramble, Kenneth M. Brown, Constantine Dafermos, Roger Farrell, Michael E. Fisher, Wolfgang H. J. Fuchs, Leonard Gross, Frederick Jelinek, Harry Kesten, Jack Kiefer, James A. Krumhansl, Simon A. Levin, G. S. S. Ludford, Anil Nerode, Lawrence E. Payne, Narahari U. Prabhu, Sol Rubinow, Edwin E. Salpeter, Alfred H. Schatz, William R. Sears, A. Richard Seebass, Shan-fu Shen, Frank L. Spitzer, Benjamin Widom, Jacob Wolfowitz, Tai T. Wu.

Field Representative: Lawrence E. Payne, 275 Olin Hall.

**MAJOR SUBJECT.** Applied Mathematics. The graduate program in Applied Mathematics is based on a solid foundation in pure mathematics; it includes a thorough grounding in mathematical methods and studies of subject areas in which significant applications of mathematics are made. A new program of study in the area of mathematical biology has recently been initiated through the help and cooperation of the Biomathematics Group at the Cornell Medical School.

**MINOR SUBJECTS.** In consultation with the major advisor minor subjects may be chosen from those available in the biological, engineering, physical, and social sciences. One minor subject must be chosen in some area outside of mathematics and applied mathematics. Only one minor subject is required.

**ADMISSION REQUIREMENTS.** Graduate students from a variety of educational backgrounds, including the several branches of engineering and the physical and biological sciences as well as mathematics will be admitted to study in this Field.

**LANGUAGE REQUIREMENT.** A candidate for the degree of Ph.D. must demonstrate reading ability by passing an ETS examination in French, German, or Russian.

**OTHER FIELD REQUIREMENTS.** To be admitted to the candidacy for the Ph.D. degree or to obtain a Master's degree a student must satisfy the following requirements:

A. He must be familiar with advanced calculus (Math 411-412) and elementary abstract algebra (Math 431-432).

B. He must have satisfactorily completed Math 415-416 or Mechanics 1182-1183.

C. He must pass one of the following combinations of subjects in mathematics: (1) 511-512, (2) 521-522, (3) 521-531, (4) 511-531. Requirement A may be met either by a satisfactory grade on the written examination administered by the Department of Mathematics in September, or by taking and mastering these courses with a high degree of competence. The Admission to Candidacy Examination will consist of the final examinations in the required courses followed by an oral examination given by the candidate's committee. Normally a student will be able to satisfy these candidacy requirements at the end of his second year, but in each individual case the student's committee will decide the appropriate timing.

Each candidate for the degree must acquire familiarity with significant

<sup>1</sup> Ordinarily the minor subject for candidates whose major subject is in engineering or science should be mathematics. Applied mathematics will be available as a minor subject only in unusual cases when a minor in mathematics does not meet the educational objectives.

applications of advanced mathematics. Such applications may be studied at Cornell in several areas such as the various fields of engineering, biology, physics, chemistry, mathematics, and computer science. The specific courses may be chosen by the student with the consent of his special committee.

The thesis in Applied Mathematics must be a mathematical contribution toward the solution of a problem arising outside mathematics.

## Areas of Interest

- M. S. Balch, Assistant Professor of Mathematics: methods of applied mathematics, elliptic differential equations.
- L. J. Billera, Assistant Professor of Operations Research: game theory, combinational mathematics.
- H. D. Block, Professor of Theoretical and Applied Mechanics: nonlinear mechanics, automata, functional analysis.
- J. H. Bramble, Professor of Mathematics: numerical analysis and partial differential equations.
- K. M. Brown, Assistant Professor of Computer Sciences: numerical analysis.
- R. Farrell, Professor of Mathematics: probability and statistics.
- M. E. Fisher, Professor of Mathematics and Chemistry: foundation and applications of statistical mechanics.
- W. H. J. Fuchs, Professor of Mathematics: mathematical methods of physics.
- L. Gross, Professor of Mathematics: analysis, mathematics of quantum theory.
- F. Jelinek, Associate Professor of Electrical Engineering: information theory, coding, communication networks, automata.
- H. Kesten, Professor of Mathematics: probability theory.
- J. C. Kiefer, Professor of Mathematics: probability and statistics.
- J. A. Krumhansl, Professor of Physics: mathematical physics, microscopic processes, macroscopic descriptions.
- S. Levin, Assistant Professor of Mathematics: mathematical analysis, partial differential equations, biomathematics.
- G. S. S. Ludford, Professor of Applied Mathematics: fluid mechanics, magneto-fluid dynamics.
- A. Nerode, Professor of Mathematics: mathematical logic, recursive functions and computability, algebra, automata.
- L. E. Payne, Professor of Mathematics: partial differential equations.
- N. U. Prabhu, Professor of Operations Research: stochastic processes, queues and inventories, reliability.
- S. Rubinow, Professor of Biomathematics (Cornell Medical College): blood flow, cell proliferation.
- E. E. Salpeter, Professor of Physics and Astronomy: theoretical astrophysics, nuclear theory, statistical mechanics.
- A. H. Schatz, Assistant Professor of Mathematics: partial differential equations.
- W. R. Sears, John L. Given Professor of Engineering: aerodynamics, magneto-fluid dynamics.
- A. R. Seebass, Associate Professor of Aerospace Engineering: aerodynamics, magneto-fluid dynamics.
- S. F. Shen, Professor of Aerospace Engineering: aerodynamics, rarefied gas-dynamics.
- F. L. Spitzer, Professor of Mathematics: probability theory and analysis.
- B. Widom, Professor of Chemistry: physical chemistry, statistical mechanics.



- J. Wolfowitz, Professor of Mathematics: mathematical statistics, probability, information theory.  
 T. T. Wu, Assistant Professor of Biomathematics (Cornell Medical College): molecular biology, bacterial genetics.

## APPLIED PHYSICS

Faculty: Peter L. Auer, Joseph M. Ballantyne, Robert W. Balluffi, Boris W. Batterman, John M. Blakely, K. Bingham Cady, David D. Clark, Roderick K. Clayton, Terrill A. Cool, Edmund T. Cranch, Trevor R. Cuykendall, P. C. Tobias de Boer, Lester F. Eastman, Michael E. Fisher, Hans H. Fleischmann, Thomas Gold, Paul L. Hartman, Martin O. Harwit, Herbert H. Johnson, James A. Krumhansl, Charles A. Lee, Che-Yu Li, Richard L. Liboff, Paul R. McIsaac, Ross McPherson, Mark S. Nelkin, Edwin L. Resler, Jr., Thor N. Rhodin, Norman Rostoker, Arthur L. Ruoff, Henri S. Sack, Miriam H. Salpeter, David N. Seidman, Benjamin M. Siegel, John Silcox, Ravindra N. Sudan, Chung-Liang Tang, Anthony Taylor, Donald L. Turcotte, Watt W. Webb, George J. Wolga.

Field Representative: Watt Webb, Clark Hall.

### MAJOR AND MINOR SUBJECT

Applied Physics

**OBJECTIVES.** Graduate study in the Field of Applied Physics offers the opportunity to achieve proficiency in physics, mathematics, and applied science. The course program resembles a major in physics, and applied physics is particularly suitable for students preparing for a scientific career in areas of applied science based on principles and techniques of physics and in associated areas of physics. It provides a means for students with undergraduate training in physics to branch out into applied science while continuing the study of physics, and for students with backgrounds in engineering or another science to extend their knowledge of physical science principles and techniques.

A student may choose for specialization and thesis research any subject that is compatible with an approach based on the application of principles of physics and mathematics. Individual programs of study are planned to meet the needs and interests of each student, and programs involving several academic disciplines and topics that are undergoing transition from fundamental physics to applied science are readily accommodated.

Current areas of advanced study and research include: applied theoretical physics, biophysics, chemical physics, physics of fluids, nuclear and reactor physics, optics, plasma physics, radiation and matter, solid state physics and materials sciences, space physics, and surface physics.

## Degree Programs

Ordinarily graduate students in applied physics enter as candidates for the Ph.D. The Master of Science degree can also be awarded either for two years of formal course study without a thesis plus satisfactory performance on a comprehensive examination, or for a shorter program of formal study accompanied by a master's thesis.

## PROFESSIONAL DEGREE

The objectives of the four-year engineering physics program are well served by an additional year of advanced study leading to the degree of Master of Engineering (Engineering Physics). The student has the opportunity to master advanced topics in physics and can extend his skill in his chosen engineering specialties. He must carry out an independent project that provides experience in defining objectives, making plans, prosecuting a program and reporting conclusions. Thus he is expected to develop and display the skills and the responsibility needed for working independently or co-operatively toward engineering goals without firmly prescribed guide lines other than his own knowledge and judgment.

From the Master's Program the student may move into development work, for example in industry, or he may go on to more advanced graduate study, either in the Field of Applied Physics or in some other related field.

Most of the laboratory facilities for research in the areas described above are made available for the student projects required for the M.Eng. degree. Each project is supervised by a member of the faculty active in the subject.

### ADMISSION REQUIREMENTS FOR THE PROFESSIONAL DEGREE.

(1) For Cornell students: A grade point average of 2.5 or higher in the four-year Field Program in engineering physics will allow admission without petition. (2) For transfer students: Evidence is required that the candidate has the ability and preparation to complete successfully the program of study.

**REQUIREMENTS FOR THE PROFESSIONAL DEGREE.** (1) An informal study, or project, of at least six credit hours value, which requires individual effort and a formal report, and which may be either experimental or analytical. (2) (a) If the project is experimental, one course in mathematics or applied mathematics; or (b) if it is analytical, one term of advanced laboratory, Physics 510, or an equivalent laboratory course to be taken upon approval by the curriculum committee of the department. (3) Physics 572, Quantum Mechanics. (4) A minimum of six hours in an engineering course sequence. (5) Chemistry 380, 596 or a new equivalent course to be arranged. (6) A seminar course—a modified version of 8252. One credit hour or more by arrangement. (7) Technical electives to bring the total credit hours to thirty.

## M.S. OR PH.D. DEGREE

**ADMISSION REQUIREMENTS.** Undergraduate preparation in physics, or other physical science, or in an engineering field with strong emphasis on mathematics and modern physics provides appropriate preparation for graduate work in Applied Physics. Applicants are judged with respect to evidence of quality and capability to benefit by graduate study in Applied Physics. Academic achievement in undergraduate program, technical experience, and recommendations of teachers and supervisors are carefully considered. Although not required, it is strongly suggested that Graduate Record Examination scores be submitted. The applications of students seeking to return to graduate school after a period of professional employment subsequent to their undergraduate training are welcomed.

**LANGUAGE REQUIREMENT.** A reading knowledge of one modern language is required for the Ph.D. degree. There is no language requirement for the M.S. degree.

**EXAMINATION REQUIREMENTS.** Every student in the Ph.D. program takes a written qualifying examination after three semesters of graduate study. This examination covers the "core" course program. Shortly after this the candidate is given the Ph.D. Candidacy Examination by his Special Committee. The Candidacy Examination may be either oral, or written and oral. After it is passed, the emphasis in the candidate's program is expected to be on independent research leading to the Ph.D. thesis. Formal courses taken after the Candidacy Examination are usually in areas close to the candidate's research specialty. After the Ph.D. thesis is completed the student is examined on his thesis by his Special Committee.

## Financial Aid

Graduate students in Applied Physics usually receive financial aid during their entire graduate study program provided only that they are making satisfactory progress toward an advanced degree. However, financial aid for a foreign student is not usually available his first year. Financial aid is available through fellowships, research assistantships, teaching fellowships, and tuition and fees scholarships.

For information about fellowships available through Cornell University, see pages 14-17 in this *Announcement*. In addition, there are several fellowships restricted to graduate students in Applied Physics.

Most students in Applied Physics hold appointments as teaching fellows or research assistants during the first and second years, and usually as research assistants during subsequent years including the period of thesis research. The initial assignments of students who begin graduate work with support as research assistants are planned to concur with their interests as closely as they can be identified.

During the summer, teaching fellows and nine-month fellowship appointees are generally appointed as research assistants, and practically all advanced graduate students have stipends either as fellows or as assistants so that their thesis research can be pursued without interruption. Part-time teaching fellowships and summer appointments as research assistants available for fellowship students provide early teaching and research experience.

A teaching fellowship requires a total of about sixteen hours of work per week (including time for preparation and grading of papers); a research assistantship requires about twenty hours. Although a teaching fellow or a research assistant usually registers for three courses each term (instead of the possible full-time load of four courses), he is nevertheless considered to be a full-time student, earns full residence credit, and his progress toward an advanced degree is not materially impeded by his duties.

## Opportunities for Advanced Study and Research

Applied theoretical physics: Quantum mechanics, statistical physics, applications of irreversible thermodynamics, cooperative phenomena, transport theory, band structures, quantum electronics, atomic basis of hydrodynamics, plasmas, superfluids, molecular theory of liquids, phase stability.

Biophysics: Electron microscopy, autoradiography, cell biology, photosynthesis, nuclear techniques in biophysics.

Chemical physics: Phase transitions, critical phenomena, chemical kinetics.

Cryogenics: Superconductivity, superfluids.

Fluid physics: Transport theory, light scattering, critical and collective phenomena, superfluids.

Nuclear and reactor physics: Low energy nuclear physics (reactions, isomers, isobaric analog states, fission), neutron physics, nuclear instrumentation (development of detectors and techniques, new applications in engineering and biology), activation analysis, reactor theory, experimental reactor physics.

Optics: Lasers, optical coherence and statistical optics, electron optics and high resolution electron microscopy, light scattering and high resolution spectroscopy, x-ray and electron diffraction, scattering and imaging, non-linear optics, optical properties of solids.

Plasma physics: Magnetohydrodynamics, solid state plasmas, shocks and fast reactions, plasma instabilities, energy conversion, controlled nuclear fusion, astrophysical plasmas.

Radiation and matter: Solid state electronics at microwave through visible frequencies, radiation damage, excited state atomic and molecular spectroscopy, x-ray and electron scattering.

Solid state physics: Crystal defects, diffusion and conduction, dislocation mechanics, flow and fracture, elasticity, internal friction, electronic properties of metals, ionic crystals and semiconductors, superconductivity, ferromagnetism, electron spin resonance, high pressure properties. (For further details of programs in this area, see the description of programs of the Materials Science Center, page 47.

Space physics: Atmospheric and ionospheric investigations, physical phenomena in astronomy and astrophysics, radio astronomy. (Further details of some programs in this area are given in the description of programs of the Center for Radiophysics and Space Research, page 45.

Surface physics: Atomistic properties of solid surfaces, interfacial phenomena in liquid and solids, physical electronic behavior, theory and application of low energy electron diffraction and field ionization, physical properties and morphology of surface phases.

Because many of the faculty of the Field of Applied Physics are also members of other fields and research centers, graduate students in Applied Physics can readily cross interdisciplinary boundaries and gain access to extensive research facilities. Additional details about current programs are described in bulletins available from the Field Representative for Applied Physics.

## Courses of Instruction

Graduate study in Applied Physics is based on a firm knowledge of the fundamentals of physics and mathematics. Although there are no formal course requirements, a "core" program with substitutions or variations is recommended. Because of the policy of interlocking instruction with more specialized groups the course programs are based primarily on courses administered by other fields. Thus the listings given by the appropriate fields should be consulted for course descriptions. The course program of a typical graduate student entering directly from an undergraduate major in physics is likely to be as follows:

First year, first term:

Physics 510, Advanced Experimental Physics

Physics 561, Theoretical Physics I  
Math 415, Mathematical Methods in Physics

First year, second term:

Physics 572, Quantum Mechanics  
Physics 562, Theoretical Physics II  
Math 416, Mathematical Methods in Physics

Variations on this core program include substitution of Math 421, 422, or 423 for those with weaker preparation in mathematics, or inclusion of advanced undergraduate level courses in physics such as Physics 326, 356, 431, 432, or 443 for those whose undergraduate preparation in physics is less extensive. Many students are also able to enter at a more advanced level or carry additional courses. Commonly included either during the first or second year are:

Physics 574, Intermediate Quantum Mechanics  
Physics 612, Experimental Techniques in Atomic and Solid State Physics  
Physics 505-506, Design of Electronic Circuitry

Physics 510 and 574 are usually available during the summer. A common substitution is Chemistry 596, Statistical Mechanics, for Physics 562. The core program assumes that all students will extend their knowledge of quantum mechanics beyond the level of Physics 572, perhaps by study of an application of quantum mechanics in a research specialty.

Specialization at the advanced level is based on the foundation gained in these core courses. Many combinations are possible, and each program is worked out individually. However, some of the courses available in various typical specializations are listed below. This list is not comprehensive, and offerings listed in other fields should be consulted for other topics and for course descriptions.

Nuclear physics:

Physics 645, Nuclear Physics  
Physics 574, Intermediate Quantum Mechanics  
Physics 657, Theory of Nuclei  
Engineering 8309, Low-Energy Nuclear Physics  
Engineering 8312, Nuclear Reactor Theory  
Engineering 8313, Reactor Theory II  
Engineering 8314, Neutron Transport Theory  
Engineering 8351, Nuclear Measurements Laboratory  
Engineering 8352, Advanced Nuclear and Reactor Laboratory  
Engineering 8333, Nuclear Reactor Engineering  
Engineering 8336, Nuclear Materials

Plasma physics:

*Magnetohydrodynamics*  
Engineering 7201 and 7202, Magnetohydrodynamics I and II  
Engineering 7203, Advanced Topics in Plasma-Dynamics I  
Engineering 4565 and 4566, Radiophysics of the Atmosphere I and II

*Theoretical plasma physics*  
Engineering 4561 and 4562, Plasma Physics I and II  
Engineering 4661, Kinetic Equations  
Engineering 4662, Kinetic Theory of Plasma

*High temperature molecular physics*  
Engineering 7101 and 7102, Advanced Kinetic Theory; Gasdynamics  
Chemistry 580, Kinetics of Chemical Reactions  
Chemistry 598, Selected Topics in Physical Chemistry  
Engineering 7103, Dynamics of Rarefied Gases

*Astrophysical plasmas*

- Astronomy 520 and 521, Radio Astronomy I and II
- Astronomy 524, Radio Waves in Ionized Gases
- Astronomy 532, Physics of the Magnetosphere
- Astronomy 560, Theory of Stellar Structure and Evolution

Quantum electronics:

- Engineering 4511, Electrodynamics
- Engineering 4514, Microwave Theory
- Engineering 4520, Graduate Laboratory
- Engineering 4531 and 4532, Quantum Electronics I and II
- Engineering 4535 and 4536, Semiconductor Devices I and II
- Engineering 4538, Electromagnetic Properties of Solids
- Engineering 4631, Advanced Microwave Electronics

Solid state physics and materials science:

- Physics 635, Solid State Physics
- Physics 636, Advanced Solid State Physics
- Physics 654, Theory of Many-Particle Systems
- Physics 680, Special Topics in Solid State Physics
- Engineering 4531 and 4532, Quantum Electronics I and II
- Engineering 4538, Electromagnetic Properties of Solids
- Engineering 6601, Topics in Thermodynamics and Kinetics
- Engineering 6602, Phase Transformations
- Engineering 6603, Crystal Mechanics
- Engineering 6604, Dislocations
- Engineering 6605, Electrical and Magnetic Properties of Engineering Materials
- Engineering 6606, Mechanical Behavior of Materials
- Engineering 6611, Principles of Diffraction
- Engineering 6762, Physics of Solid Surfaces
- Engineering 6872, Nuclear Materials
- Chemistry 578, Thermodynamics
- Chemistry 580, Kinetics of Chemical Reactions
- Chemistry 589, X-Ray Crystallography
- Chemistry 594, Quantum Mechanics II

Space physics:

- Engineering 4561 and 4562, Plasma Physics I and II
- Engineering 4565 and 4566, Radiophysics of the Atmosphere I and II
- Engineering 4567 and 4568, Advanced Antenna Methods and Problems I and II
- Astronomy 431, Introduction to Astrophysics
- Astronomy 432, Introduction to Space Physics
- Astronomy 510, Cosmology and Evolution
- Astronomy 520 and 521, Radio Astronomy I and II
- Astronomy 524, Radio Waves in Ionized Gases
- Astronomy 531, Cosmic Rays
- Astronomy 532, Physics of the Magnetosphere
- Astronomy 560, Theory of Stellar Structure and Evolution

## Courses Administered by Applied Physics

Courses at the advanced undergraduate and graduate level administered by Applied Physics and not listed elsewhere in the *Graduate School Announcement* follow.

**EP 8121. THERMODYNAMICS AND FLUID MECHANICS**

Fall term. Credit three hours.

Classical thermodynamics and applications; compressible one-dimensional flows and shock waves; introduction to fluid mechanics. The general level of sophistication expected in 8121-8122 is that of the fourth-year student in engineering physics.

**EP 8122. STATISTICAL MECHANICS AND KINETIC THEORY**

Spring term. Credit three hours. Prerequisite: 8121 or its equivalent.

Ensembles and partition functions, ideal quantum and classical gases, imperfect gases, distribution and correlation functions. Random walks and Brownian motion, fluctuations, kinetic theory. At the level of F. Reif, *Fundamentals of Statistical and Thermal Physics*.

**EP 8133. MECHANICS OF PARTICLES AND SOLID BODIES**

Fall term. Credit three hours. Three recitations.

Newton's laws, harmonic oscillator. Fourier series and Green's function solutions. Lagrange equations, Hamiltonian formalism, Central force motion, orbits, scattering, cross-sections. Many particle dynamics, Lagrangian formulations, Lorentz transformation.

**EP 8134. MECHANICS OF CONTINUA**

Spring term. Credit three hours. Three recitations.

Mechanics of continua, equilibrium, propagation of sound waves. Elasticity, torsion, shear, bending stresses.

**EP 8205. ELECTRICAL AND MAGNETIC PROPERTIES OF ENGINEERING MATERIALS**

Fall term. Credit three hours. Prerequisite: Physics 454 or consent of the instructor.

Electrical properties of semiconductors. Metallic alloys. Ferromagnetic materials. Superconductivity. Optical and dielectric properties of insulators and semiconductors. At the level of Kittel, *Introduction to Solid State Physics*; Chikazumi, *Physics of Magnetism*; Lynton, *Superconductivity*; Livingston and Schadler, *The Effect of Metallurgical Variables on Superconductivity Properties*.

**EP 8211. PRINCIPLES OF DIFFRACTION**

Fall term. Credit three hours. Offered jointly with the Department of Materials Science and Engineering.

Production of neutrons, x rays, absorption, scattering, Compton effect. Diffraction from periodic lattices, crystal symmetry, single crystal and powder techniques. Fourier methods, thermal vibration and scattering, diffraction from liquids and gases, introduction to dynamical diffraction of x rays and electrons, extinction phenomena and perfect crystals. Selected experiments in diffraction.

**EP 8212. SELECTED TOPICS IN DIFFRACTION**

Spring term. Credit three hours. Three lectures. Prerequisite: 8211. Offered jointly with the Department of Materials Science and Engineering.

Dynamical diffraction: Ewald-von Laue theory of dynamical diffraction applied to x rays and electrons. Currently developing theory and application to defects in solids. Phenomena investigated via diffuse scattering: phonons, measurement of dispersion curves, frequency spectrum, Debye temperatures, vibrational amplitudes. Order-disorder phenomena: short- and long-range

order, Guinier-Preston zones. Selected topics of current interest related to x ray, neutron, and electron diffraction, with contributions from several members of the faculty.

#### EP 8252. SELECTED TOPICS IN PHYSICS OF ENGINEERING MATERIALS

Fall term. Credit one hour. Primarily for candidates for Master of Engineering (Engineering Physics); others with consent of the instructor.

Seminar-type discussion of special topics in the field of engineering materials, such as plastic and rheological properties; dielectric and magnetic behavior; semiconductors; radiation damage; etc. Emphasis is given to the interpretation of the phenomena in light of modern theories in physics of solids and liquids and their impact on the engineering applications. Current literature is included in the assignments.

#### EP 8262. PHYSICS OF SOLID SURFACES

Spring term. Credit three hours. A lecture course for graduate students and upperclassmen offered jointly with the Department of Materials Science and Engineering.

An introductory critical review of advances in the theory of the solid-state related directly to surface phenomena. Thermodynamics of surface phases, atomistic theory of surfaces and dynamics of interaction of electrons, ions and atoms with surfaces are considered. Reference is made to application of the theory to surface and interface phenomena in metals, insulators and semiconductors, as much as possible. Presented at the level of *Advances in Solid State Physics*, Ed., Seitz and Turnbull.

#### EP 8601. PHYSICAL APPROACHES TO PROBLEMS OF PHOTOSYNTHESIS

Fall term. Credit three hours. Given in alternate years. Prerequisites: Chemistry 104 or 108, Mathematics 112, Physics 208, or permission of the instructor.

Emphasis is on physical and photochemical mechanisms and physical experimental approaches. Photosynthetic organisms; their photochemical apparatus, metabolic pathways, and mechanisms for energy conversion. Descriptive introduction to the physics of excited states in molecules and molecular aggregates. Optical and photochemical properties of chlorophyll, and of the living photosynthetic tissue. Contemporary investigations of the photosynthetic mechanism. The level of the course can be judged by consulting R. K. Clayton, *Molecular Physics in Photosynthesis* (Blaisdell Publishing Co., Waltham, 1965).

#### EP 8603. GENERAL PHOTOBIOLOGY

Fall term. Credit three hours. Prerequisites: Chemistry 104 or 108, Mathematics 112, Physics 208, or the permission of the instructor. Given in alternate years.

A survey of systems of current interest in photobiology, including photosynthesis, bioluminescence, vision, photoperiodism, and the action of ultraviolet light on nucleic acids. Physical concepts and methodologies are emphasized.



## ASTRONOMY AND SPACE SCIENCES

Faculty: Ralph Bolgiano, Neil M. Brice, John P. Delvaille, Frank D. Drake, Donald T. Farley, Thomas Gold, Kenneth I. Greisen, Martin O. Harwit, Cyril Hazard, Frederick Jelinek, Richard L. Liboff, George H. Morrison, Edwin L. Resler, Jr., Henri S. Sack, Carl E. Sagan, Edwin E. Salpeter, R. William Shaw, Ravindra N. Sudan, Yervant Terzian, Robert Wagoner.

Field Representative: Martin O. Harwit, 212 Space Science Building.

### MAJOR AND MINOR SUBJECTS

Astronomy	Radiophysics
Astrophysics	Space Sciences (General)
Magnetohydrodynamics	

Students wishing to apply for admission to Cornell University in the Field of Astronomy and Space Sciences should submit a completed application form, two letters of recommendation, and a transcript of previous academic work. Scores obtained on the Graduate Record Examination are optional; but these often are of great help in admitting outstanding students from less known institutions, or from colleges which previously have not had students attend Cornell.

Students wishing to transfer into the Field of Astronomy and Space Sciences from other fields at Cornell should apply for admission early in February. Their applications will then be considered together with those of new applicants from outside the University.

There is no language requirement for the Master's degree. The language requirement for the Ph.D. degree consists of proficiency in one of the following: French, German, or Russian.

Examinations required by the Graduate School are described on page 12 of this *Announcement*. In addition to these, the Field of Astronomy and Space Sciences expects the graduate student to pass a qualifying examination at the beginning of his second year of graduate study.

The major and both minor subjects for the doctorate should not all be chosen in this Field.

Students may come to this Field with a strong background in astronomy, electrical engineering, engineering physics, mathematics, or physics.

Members of the staff are particularly interested in directing graduate research in the following subjects:

Astronomy and astrophysics: cosmic rays, cosmology, dynamics of the interstellar gas, geodetic astronomy, lunar photometry, solar system magnetohydrodynamics, stellar spectroscopy, theory of stellar structure, stellar evolution, nuclear processes in stars, stellar statistics.

Atmospheric and ionospheric radio investigations: dynamics of the atmosphere and ionosphere; incoherent electron scattering; study of refraction, scattering, attenuation due to the inhomogeneous nature of the troposphere and ionosphere; theory and observation of propagation of radio waves in ionized media such as the ionosphere.

Radio astronomy: distribution and classification of radio sources, radar investigations of the moon and planets, solar radio observations; studies of gaseous nebulae.

Space vehicle instrumentation: instrumentation relating to lunar exploration, magnetic field measurements, tenuous gas and particle flux measurements; infrared observations from rockets.

Infrared astronomy: observational and theoretical studies of dust clouds, ionized hydrogen regions, and cosmic background.

Planetary astronomy: study of the atmospheres of planets, radar and infrared observations, exobiology.

Graduate students in this Field may be connected with the Cornell University Center for Radiophysics and Space Research. Many members of the faculty listed above are members of this Center, which possesses or is planning important facilities for geophysical and solar system investigations both by radio methods and by space vehicle instrumentation. Further details of this organization and facilities can be obtained by writing to the Secretary, Cornell University Center for Radiophysics and Space Research, Space Science Building. See also page 12.

The recently formed Cornell-Sydney University Astronomy Center, an international cooperative venture in the Field of Astronomy and Space Sciences, provides students and faculty members of the two universities with an opportunity to work together in the field. The Sydney University facilities include the Criss-Cross and Mills Cross radio telescopes, the stellar intensity interferometer, detectors for very high energy cosmic rays, and plasma and nuclear physics laboratories. Further details can be obtained by writing to the Secretary, Astronomy Department, Space Sciences Building. See also page 46.

## Courses

### 431. INTRODUCTION TO ASTROPHYSICS

Fall term. Credit three hours. Prerequisites: Physics 225, 226, and 303 or the equivalent. Mr. Harwit.

Dynamics of planetary and stellar systems. Stellar structure and evolution. Binary, variable and peculiar stars. Nuclear synthesis in stars. Stellar atmospheres. Abundance of the chemical elements.

### 432. INTRODUCTION TO SPACE PHYSICS

Spring term. Credit three hours. Prerequisite: 431 or consent of the instructor. Mr. Harwit.

Interstellar dust and gas. Evolution of the Stromgren sphere. Star formation. Interstellar magnetic fields, cosmic rays and radio emission. Interplanetary gas and dust. Comets, meteorites, and micrometeorites.

### 510. COSMOLOGY AND EVOLUTION

Spring term. Credit three hours. Offered on sufficient demand. Open to graduate students with the consent of the instructor. Messrs. Gold and Wagoner.

Relativistic astrophysics. Cosmological models and tests of models. Evolution of stars and galaxies. Quasars.

### 520. RADIO ASTRONOMY I

Fall term. Credit three hours. Prerequisite: 330, or graduate status, or consent of the instructor. Messrs. Drake and Terzian.

Radio astronomy telescopes and electronics. Preferred observing procedures and data analysis. Concepts of aperture synthesis. Physical mechanisms of radio emission. Radio and radar studies of the solar system. Physical nature of the sun, moon, and planets as deduced from radio sources.

### 521. RADIO ASTRONOMY II

Spring term. Credit three hours. Prerequisite: 520. Messrs. Drake and Terzian.

Thermal and nonthermal radiation from the galaxy. Supernova remnants.

Relation of galactic emission to cosmic rays. Galactic 21-cm. emission. Galactic structure and kinematics as inferred from radio observations. Radio emission from normal and abnormal galaxies. Quasi-stellar radio sources. Physical theories of the quasi-stellar sources and abnormal radio galaxies.

#### 524. RADIO WAVES IN IONIZED GASES

Spring term. Credit three hours. Prerequisite: 520 or consent of the instructor. Staff.

Propagation of radio waves in inhomogeneous plasma. Scattering by irregularities. Generation and absorption of radio waves. Scintillations. Applications to the theory of radio emission by the sun and by Jupiter.

#### 530. NUCLEAR ASTROPHYSICS

Fall term. Credit three hours. Prerequisite: graduate status with good physics background. Mr. Wagoner. Given in alternate years.

Observations of the abundances of nuclear species; nucleogenesis; the production of the nuclear species in stars; slow and rapid processes; supernovae; abundances in different stars; the abundance of helium; nuclear species in evolutionary cosmologies.

#### 531. COSMIC RAYS

Fall term. Credit three hours. Prerequisite: consent of the instructor. Staff. Given in alternate years.

Motion of high energy particles through interstellar and interplanetary space. Solar particles and sun-earth relations. Intensity time variations. Cosmic rays in the geomagnetic field. Cosmic rays in the galaxy. The origin of cosmic rays.

#### 532. PHYSICS OF THE MAGNETOSPHERE

Spring term. Credit three hours. Prerequisite: consent of the instructor. Staff. Given in alternate years.

Interaction between charged and neutral components of the ionosphere. Tidal theory of regular magnetic variations. Equatorial anomaly. Sporadic E. Structure and composition of the ionosphere. VLF and ELF emissions. Radiation belts. Aurora. Magnetic storms.

#### 540. ADVANCED STUDY AND RESEARCH

Either term. Credit one to four hours a term. Prerequisites: advanced standing in astronomy and consent of the instructor. Staff.

Upon sufficient demand, seminars will be arranged from time to time in topics not currently covered in regular courses. Typical seminar subjects are high energy particles in astronomy, planetary and lunar physics, and geophysics.

#### 550. INTERSTELLAR MATTER

Fall term. Credit three hours. Mr. Terzian.

The study of emission, reflection, and dark nebulae. Interstellar absorption and reddening. Planetary nebulae, novae and supernovae shells. Neutral hydrogen distribution in the galaxy. Interstellar gas dynamics.

#### 560. THEORY OF STELLAR STRUCTURE AND EVOLUTION

Fall term. Credit three hours. Prerequisite: graduate status with good physics background. Given upon sufficient demand (usually in alternate years). Staff.

Summary of observational facts. Dimensional analysis. Nuclear reactions in

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stars. Models for static and evolving stars. Very massive objects and general relativity. White dwarfs and neutron stars.

### 570. PHYSICS OF THE PLANETS

Fall term. Credit three hours. Prerequisite: graduate status with good physics background. Mr. Sagan.

Physics and chemistry of planetary atmospheres, surfaces and interiors. The roles of convective, conductive and radiative energy; optical, infrared, radio, radar and space-probe information. Applications to exobiology and to the earth as a planet.

### 571. SPECIAL PROBLEMS IN PLANETARY ASTRONOMY

Spring term. Credit two hours. Prerequisite: 570. Mr. Sagan.

## BIOMATHEMATICS (GRADUATE SCHOOL OF MEDICAL SCIENCES)

See pages 51, 154, and 155.

## BIOPHYSICS (GRADUATE SCHOOL OF MEDICAL SCIENCES)

See pages 51 and 155.

## BIOSTATISTICS (GRADUATE SCHOOL OF MEDICAL SCIENCES)

See pages 51 and 155.

## CHEMICAL ENGINEERING

Faculty: George G. Cocks, Victor H. Edwards, Robert K. Finn, Peter Harriott, Jay E. Hedrick, Jean P. Leinroth, Jr., Ferdinand Rodriguez, George F. Scheele, Julian C. Smith, Raymond G. Thorpe, Robert L. Von Berg, Herbert F. Wiegandt, Charles C. Winding, Robert York.

Field Representative: Charles C. Winding, 124 Olin Hall.

### MAJOR AND MINOR SUBJECTS

Biochemical Engineering  
Chemical Engineering, General  
Chemical Processes and  
Process Control

Materials Engineering  
Nuclear Process Engineering

To qualify for admission, a student must have completed satisfactorily the equivalent of the fundamental work required by an accredited curriculum in chemical engineering. Outstanding students who have received a baccalaureate degree with a major in chemistry will also be considered for admission. Normally an extra year of residence is required of such students to make up work in engineering fundamentals.

A student in a Ph.D. program must demonstrate reading ability in one foreign language chosen from French, German, or Russian. There is no language requirement for the M.S. degree.

"Chemical Engineering, General" is required of all students, either as a major or as a minor. Ph.D. candidates are required to select one minor within the Field and one minor outside the Field. M.S. candidates may choose a minor which can be within or outside the Field. Each M.S. candidate must pass an oral examination on his major and minor subjects and on his thesis. Two examinations are required before a student is designated as a Ph.D. candidate. On recommendation of the faculty, a student will be admitted to the written Field Examination. When this examination has been passed to the satisfaction of the faculty of the Field, the student takes an oral comprehensive Admission to Candidacy Examination administered by his Special Committee. After the thesis has been completed, an oral Final Examination, administered by the Special Committee and covering the thesis and related topics, must be taken.

Candidates are expected to pursue a course of study and research that will give them a deeper comprehension of the basic and applied sciences and will develop initiative, originality, and creative ability. To achieve this goal the student participates in graduate courses and seminars and must complete an original, individual investigation for a thesis. Theses may involve either experimental research or special projects in such subjects as design, economics, and mathematical analysis. Specific programs are planned to fit the objectives of the student and to develop original thinking. An arbitrarily fixed series of courses is not required, but each student is expected to acquire a strong background in applied mathematics, chemical processes, rate and mass transfer processes, reaction kinetics, and thermodynamics. Outside minor subjects may be chosen from a wide variety of other Fields consistent with the student's objectives.

## Research Opportunities

Fluid dynamics, heat transfer, mass transfer, reaction kinetics, stage processes, and thermodynamics may be regarded as the fundamentals of chemical engineering. The Cornell staff is actively working on or has interests in many such projects. Although particular projects actively in progress are continually changing, some recent, specific research interests of particular staff members are:

George G. Cocks: microscopy, properties of materials, solid state chemistry, crystallography.

Victor H. Edwards: kinetics and process control in fermentation.

Robert K. Finn: continuous fermentation, agitation and aeration, processing biochemicals, electrophoresis, microbial conversion of hydrocarbons.

Peter Harriott: chemical kinetics and reactor design, process control, diffusion in membranes and porous solids.

Jay E. Hedrick: economic analyses and forecasts.

Jean P. Leinroth: adsorption, residence time distribution, chemical process development.

Ferdinand Rodriguez: non-Newtonian flow, Redox reactions, electrical and mechanical properties of polymer systems, rheological phenomena.

George F. Scheele: hydrodynamic stability, effect of heat transfer on flow fields.

Julian C. Smith: conductive transfer processes, flow of granular solids, heat transfer, mixing.

Raymond G. Thorpe: phase equilibria, fluid flow, kinetics of polymerization.

Robert L. Von Berg: liquid-liquid extraction, reaction kinetics, effect of radiation on chemical reactions.

Herbert F. Wiegandt: crystallization petroleum processing, saline water conversion, direct contact heat transfer.

Charles C. Winding: degradation of polymers, polymer compounding, filler-polymer systems, differential thermal analysis.

Robert York: mass transfer, diffusion, thermodynamic properties, production of shale oil, chemical market analyses.

## Professional Degree

The Master of Engineering degree is the only professional engineering degree offered by Cornell University to presently entering students.

Admission to the Master of Engineering (Chemical) degree program is open to persons who have been granted a Bachelor's degree or the equivalent, and whose background indicates that they can profitably study the advanced courses offered by the School of Chemical Engineering. The purpose of this program is to offer study in depth in both comprehensive and specialized chemical engineering subjects and to prepare students for professional careers in advanced engineering practice.

## Courses

### 5105. ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS

Spring term. Credit three hours. Three lectures. Mr. Von Berg.

Application of the general thermodynamics method to advanced problems in chemical engineering. Evaluation, estimation, and correlation of properties. Chemical and phase equilibria.

### 5106. REACTION KINETICS AND REACTOR DESIGN

Fall term. Credit three hours. Three lectures. Mr. Von Berg.

A study of chemical reaction kinetics and principles of reactor design for chemical processes.

### 5107. ADVANCED REACTION KINETICS

Fall term. Credit three hours. Three lectures. Mr. Harriott.

Effects of heat transfer, diffusion, and nonideal flow on reactor performance. Optimum design for complex reactions. Analysis of current literature on topics such as partial oxidation, catalytic cracking, hydrogenation, and polymerization.

### 5108. COLLOIDAL AND SURFACE PHENOMENA

Fall term. Credit three hours. Mr. Finn.

Lectures, demonstrations, and problems in the physics and chemistry of small particles and surface films. Topics include surface energy, surface films, electrokinetics, and colloidal behavior.

**5161. PHASE EQUILIBRIA**

Fall term. Credit three hours. Three lectures. Mr. Thorpe.

A detailed study of the pressure-temperature-composition-relations in binary and multicomponent heterogeneous systems where several phases are of variable composition. Prediction of phase data.

**5205. CHEMICAL PROCESS SEMINAR**

Fall term. Credit two hours. Mr. Wiegandt.

A discussion of recent advances in chemical process development.

**5505, 5506. ADVANCED TRANSPORT PHENOMENA**

Fall and spring term. Credit four hours each term. Messrs. Scheele and Smith.

An integrated treatment of momentum, mass and heat transfer. Molecular transport; the equations of change; viscous laminar flow of Newtonian and non-Newtonian fluids; perfect fluid theory; boundary layer theory; unsteady-state transfer; penetration theory models of mass and heat transfer; flow stability; turbulent transport; simultaneous heat and mass transfer; applications to industrial operations.

**5605, 5606, 5607, 5608. DESIGN PROJECTS**

Fall and spring terms. Credit variable. Staff.

Individual projects involving the design of chemical processes and plants. Estimation of costs of construction and operation, variation of costs and profits with rate of production, etc.

**5609. ANALYSIS AND DESIGN OF PROCESS EQUIPMENT**

Fall term. Credit three hours. Mr. Smith.

Discussion and analysis of operating principles, design, and selection of chemical process equipment.

**5621. PROCESS DESIGN AND ECONOMICS**

Fall term. Credit six hours. Mr. York.

Methods for estimating capital and operating costs. Performances, selection, design, and cost of process equipment. Process development and design. Market research and surveys.

**5622. PROCESS AND PLANT DESIGN**

Spring term. Credit six hours. Continuation of 5621. Mr. York.

Process design, including reactors, process equipment, and separating systems. Layout and model of process units. Plant location, design, and layout. Cost estimates and project evaluation, equivalent interest rate of return and discounted cash flow.

**5635. MARKETING OF CHEMICAL PRODUCTS**

Fall term. Credit three hours. Three lectures. Mr. Hedrick.

Examination of marketing activities, organizations, and costs in the distribution of chemicals. A market research project is required.

**5636. ECONOMICS OF THE CHEMICAL ENTERPRISE**

Spring term. Credit three hours. Three lectures. Mr. Hedrick.

Research economics; feasibility studies; information services; venture analysis; depreciation and amortization; planning.

**5642. DEVELOPMENT ECONOMICS**

Spring term. Credit three hours. Mr. York.

Planning, evaluation, and management of development activities in the process industries as related to research, processing, new products, markets, and long-range growth.

**5717. PROCESS CONTROL**

Spring term. Credit three hours. Two lectures, one laboratory. Mr. Harriott.

Dynamic response of processes and control instruments. Use of frequency response analysis, Laplace transforms, and electronic analogs to predict the behavior of feedback control systems.

**5741. PETROLEUM REFINING**

Spring term. Credit three hours. Three lectures. Mr. Wiegandt.

A critical analysis of the processes employed in petroleum refining.

**5742. POLYMERIC MATERIALS**

Fall term. Credit three hours. Three lectures. Mr. Rodriguez.

Chemistry of polymerization reactions, manufacture and properties of synthetic resins, fibers, plastics, and rubbers.

**5743. PROPERTIES OF POLYMERIC MATERIALS**

Spring term. Credit three hours. Prerequisite: 5742. Mr. Rodriguez.

Mechanical, electrical, and optical properties of polymers. Phenomenological aspects and molecular theories of non-Newtonian flow viscoelasticity and ultimate tensile properties.

**5745. ANALYSIS OF POLYMERIC PROCESSES**

Fall term. Credit three hours. Three lectures. Prerequisite: 5742. Mr. Hedrick.

Technical and economic evaluations of the principal processes used in manufacture of resins, plastics, and elastomers, including analyses of raw materials, reactor systems, product preparation, and problems in distribution and marketing.

**5746. CASE STUDIES IN THE COMMERCIAL DEVELOPMENT OF CHEMICAL PRODUCTS**

Spring term. Credit three hours. Three lectures. Mr. Hedrick.

Detailed analysis of specific cases involving the development of new chemical products. Particular emphasis is given to planning activities, research justification, and market forecasting. Profitability calculations and projections are required.

**5748. FERMENTATION ENGINEERING**

Spring term. Credit three hours. Two lectures, one recitation. Mr. Finn.

An advanced discussion of fermentation as a unit process. Topics include sterilization, aeration, agitation, and continuous fermentation.

**5749. INDUSTRIAL MICROORGANISMS**

Fall term. Credit one hour. One lecture. Mr. Finn.

A brief introductory course in microbiology for students with a good background in chemistry.

**5752. POLYMERIC MATERIALS LABORATORY**

Fall term. Credit two hours. One laboratory. Prerequisite: 5742. Mr. Rodriguez.

Experiments in the formation, characterization, fabrication, and testing of polymers.



**5760. NUCLEAR AND REACTOR ENGINEERING**

Spring term. Credit two hours. Two lectures. Mr. Von Berg.

Fuel processing and isotope separation, radioactive waste disposal, fuel cycles, radiation damage, biological effects and hazards, shielding power reactors.

**5857. ELECTRON MICROSCOPY**

Fall term. Credit two hours. One lecture, one laboratory. Prerequisite: a course in microscopy or special permission. Mr. Cocks.

An introduction to the principles of electron microscope, including: electron optics, the operation and care of the microscope, methods of specimen preparation, and the interpretation of electron microscopical images.

**5859. ADVANCED CHEMICAL MICROSCOPY**

Offered on demand either term. Credit variable. Mr. Cocks.

Laboratory practice in special methods and special applications of chemical microscopy.

**5900. SEMINAR**

Fall and spring terms. Credit one hour.

General chemical engineering seminar required of all graduate students majoring in the Field of Chemical Engineering.

**5903. SEMINAR IN BIOCHEMICAL ENGINEERING**

Spring term. Credit one hour. Messrs. Edwards and Finn.

Advanced topics in the engineering applications of biophysics and biochemistry. Discussion of current research in the Field.

**CHEMISTRY**

Faculty: A. C. Albrecht, S. H. Bauer, A. T. Blomquist, J. M. Burlitch, R. A. Caldwell, W. D. Cooke, V. du Vigneaud, E. Elson, R. C. Fay, M. E. Fisher, G. A. Fisk, J. H. Freed, M. J. Goldstein, G. G. Hammes, J. L. Hoard, R. Hoffmann, R. E. Hughes, E. S. Kostiner, F. A. Long, F. W. McLafferty, J. Meinwald, W. T. Miller, G. H. Morrison, H. Muxfeldt, R. A. Plane, R. F. Porter, R. R. Rye, H. A. Scheraga, M. F. Semmelhack, M. J. Sienko, D. A. Usher, B. Widom, C. F. Wilcox, Jr.

Professor-at-Large: M. Eigen.

Field Representative: Charles F. Wilcox, Jr., 312-R Chemistry Research Building.

**MAJOR AND MINOR SUBJECTS**

Analytical Chemistry  
Bio-organic Chemistry  
Biophysical Chemistry  
Inorganic Chemistry

Organic Chemistry  
Physical Chemistry  
Theoretical Chemistry

Language requirement for the Master's degree: none. Language requirement for the Ph.D. degree: proficiency in German or, with permission of student's Special Committee, Russian.

The program of graduate study in the Field of Chemistry is designed to give a broad training in the fundamental knowledge of chemistry and in

methods of research. A graduate student will ordinarily pursue these objectives by taking advanced courses, by participation in organized and informal seminars and discussions with his associates and faculty members, and by carrying out and reporting on a research project in his major subject. Special opportunities are provided by (1) the Materials Science Center at Cornell, which supports several research assistantships for graduate students in chemistry, and (2) a National Institutes of Health Training Grant which similarly provides trainee stipends for work in bio-organic and biophysical chemistry. Upon completion of their study program, graduates normally go out to positions in research laboratories or to positions involving teaching and research.

Candidates for the degree of Master of Science or Doctor of Philosophy with a major in chemistry will be expected to offer for admission the equivalent of an A.B. degree with a major in chemistry. Such training should include courses in general chemistry, mathematics, organic chemistry, physical chemistry, physics, and qualitative and quantitative analysis. Some experience with foreign languages, preferably German and either French or Russian, is also regarded as essential. In admitting students, emphasis is placed on quality of performance and promise for research as judged by those best acquainted with applicants. Unusually promising students may be admitted with deficiencies in undergraduate training. In such cases, work designed to make up the deficiencies will be required, and more than the usual period of residence may be necessary.

Proficiency tests will be required of all entering candidates for advanced degrees (M.S. or Ph.D.) with a major in chemistry. These tests are given a few days before registration for the fall term and cover the divisions of analytical, inorganic, organic, and physical chemistry. Each test will be about two and one-half hours in length and will cover material normally presented in elementary courses in the subjects listed above. The results of these tests will be used to aid the student's Special Committee in the planning of his program of study. While the results will not be considered in the usual sense of "passing" or "failing," low marks in one or more of the tests may require enrollment in elementary courses.

In addition to the regular Admission to Doctoral Candidacy Examination and Final Examination (thesis defense), those students majoring in organic chemistry are required to pass eight cumulative examinations which are offered approximately monthly throughout the year. Students making normal progress toward their Ph.D. degree will typically take sixteen such examinations.

Graduate students are encouraged to carry on research during the summer, and a number of Summer Research fellowships are available for this purpose.

Graduate students are required to register with the Department of Chemistry on the registration days at the beginning of each term. Entering students will consult with the Chairman of the Department and with professors composing their temporary Special Committees.

In addition to the courses in chemistry, attention is directed to courses in biochemistry, chemical engineering, mathematics, and physics.

A graduate student who desires to take a minor subject in Chemistry with a major subject from some field other than Chemistry will be required to offer or acquire a satisfactory background for advanced work. This will ordinarily consist of an introductory course in general chemistry and of intermediate courses prerequisite to advanced work in the minor subject in Chemistry. The work in his minor subject in Chemistry comprises advanced study planned with the approval of his Special Committee.

Specific inquiries from prospective graduate students are welcomed and should be addressed to the Field Representative or to any member of the

faculty. Applications for teaching fellowships or research assistantships should be addressed to the Field Representative of the Department of Chemistry, Chemistry Research Building. A brochure entitled *Graduate Work in Chemistry at Cornell* is available from the Field Representative.

## Courses

### 411. INORGANIC CHEMISTRY LABORATORY

Fall term. Credit four hours. Prerequisite or parallel course: 387, or consent of the instructor.

### 421. INTRODUCTION TO INORGANIC RESEARCH

Either term. Credit two or four hours. Prerequisites: 387–388 or 285–286 at an average of B or better, and consent of the instructor.

Informal advanced laboratory and library work, planned individually in consultation with a staff member, involving the preparation and characterization of inorganic substances. A written report is required.

### 457. ADVANCED ORGANIC-ANALYTICAL LABORATORY

Spring term. Credit four hours. Prerequisites: 358 and 426, or 525, or consent of the instructor.

### 465–466. ORGANIC CHEMISTRY

Throughout the year. Credit four hours a term. Prerequisite: 358. (465 is prerequisite to 466.)

Fall term: structural theory; resonance; methods of structure determination; conformational analysis and other aspects of stereo-chemistry; introduction to reaction mechanisms; synthesis and characteristic reactions of hydrocarbons. Spring term: synthesis and reactions of the principal classes of organic compounds, with an emphasis on newer developments; the application of mechanistic reasoning to synthetic problems; multi-step syntheses.

### 481. ADVANCED PHYSICAL CHEMISTRY

Fall term. Credit four hours. Prerequisite: 288 or 390.

A discussion of advanced topics in physical chemistry, including an introduction to the principles of quantum theory and statistical mechanics, atomic and molecular spectra, and elementary valence theory.

### 505–506. ADVANCED INORGANIC CHEMISTRY

Throughout the year. Credit four hours a term. Prerequisite or parallel course: 389–390 or 287–288, or consent of the instructor. (505 is prerequisite to 506.)

Theories of atomic structure and chemical bonding are applied systematically to the elements as they appear in the Periodic System, with emphasis on the stereochemistry of inorganic substances.

### 515–516. SELECTED TOPICS IN ADVANCED INORGANIC CHEMISTRY

Throughout the year. Credit two hours a term. Students may register for either term separately. Prerequisite: 390. Only grades of S or U will be given.

### 525. ADVANCED ANALYTICAL CHEMISTRY

Fall term. Credit four hours. Prerequisite: 288 or 390.

The application of molecular spectroscopy to chemical problems. Topics discussed include ultraviolet, infrared, NMR, Raman, and mass spectroscopy.

**527. ADVANCED ANALYTICAL CHEMISTRY**

Spring term. Credit four hours. Prerequisite: 288 or 390. Offered in alternate years.

An intensive examination of contemporary electroanalytical chemistry, electrode kinetics, voltammetry including polarography, coulometry, and chronopotentiometry. Study of chromatographic separation including gas chromatography. Analytical significance of nonaqueous solutions.

**565. PHYSICAL ORGANIC CHEMISTRY**

Fall term. Credit four hours. Prerequisite: 465-466 or consent of the instructor.

Mechanisms of organic reactions, with particular attention paid to the properties of reactive intermediates: carbonium ions, carbanions, free radicals, carbenes, and electronically excited molecules.

**566. PHYSICAL ORGANIC CHEMISTRY**

Spring term. Credit three hours. Prerequisite: 565 or consent of the instructor.

Quantitative aspects of organic chemistry.

**568. CHEMICAL ASPECTS OF BIOLOGICAL PROCESSES**

Fall term. Credit four hours. Prerequisites: 358 and 388 or their equivalents.

Bioenergetics, metabolic pathways, origin of life. This course forms the chemical basis for the graduate program in molecular biology.

**570. SELECTED TOPICS IN ORGANIC CHEMISTRY**

Fall term. Credit three hours. Prerequisites: 465-466 or consent of instructor.

**572. ORGANIC MECHANISMS AND ENZYME CATALYSIS**

Spring term. Credit four hours. Prerequisites: 357-358 or equivalent and a course in general biochemistry.

Enzymes, coenzymes and model systems.

**574. CHEMISTRY OF NATURAL PRODUCTS**

Fall term. Credit three hours. Prerequisites: 456 or 457, and 465-466.

Particular attention will be devoted to methods of structure determination and synthesis as applied to selected terpenes, steroids, alkaloids, and antibiotics.

**577. CHEMISTRY OF NUCLEIC ACIDS**

Fall term. Credit four hours. Prerequisites: 358 and 390 or their equivalents.

Properties, synthesis, and reactions of nucleic acids.

**578. THERMODYNAMICS**

Spring term. Credit four hours. Prerequisite: 288 or 390.

**580. KINETICS OF CHEMICAL REACTIONS**

Fall term. Credit four hours. Prerequisites: 481 and 578 or consent of the instructor.

Principles and theories of chemical kinetics; special topics including fast reactions in liquids, enzymatic reactions, shock tubes, and molecular beams.

**582. SPECIAL TOPICS IN MOLECULAR BIOLOGY**

Spring term. Credit four hours. Prerequisite: 568 or consent of the instructor. Only grades of S or U will be given.

Detailed consideration is given to several special topics selected from recent research activity in the field of molecular biology. Topics are varied from year to year.

#### 586. PHYSICAL CHEMISTRY OF PROTEINS

Spring term. Credit four hours. Prerequisite: 288 or 390.

Chemical constitution, molecular weight, and structural basis of proteins; thermodynamic, hydrodynamic, optical, and electrical properties; protein and enzyme reactions; statistical mechanics of helix-coil transition in biopolymers; conformation of biopolymers.

#### 589. X-RAY CRYSTALLOGRAPHY

Fall term. Credit four hours. Prerequisite: Physics 322 or consent of instructor. Offered in alternate years.

Space groups, reciprocal lattices, three-dimensional diffraction, interpretation of x-ray diffraction data, structure determination by Fourier synthesis.

#### 593. QUANTUM MECHANICS I

Fall term. Credit four hours. Prerequisites: 279 and Physics 303 (or coregistration in Physics 319) or their equivalents, and coregistration in Mathematics 421 (or equivalent), or consent of the instructor.

Schrödinger's equation, wave packets, uncertainty principle, WKB theory. Matrix mechanics, orbital and spin angular momentum, exclusion principle, perturbation theory, variational principle, Born-Oppenheimer approximation. At the level of Bohm, *Quantum Theory*.

#### 594. QUANTUM MECHANICS II

Spring term. Credit four hours. Prerequisite: 593 or its equivalent.

Time-dependent phenomena in quantum mechanics and interaction with radiation. Group theory and applications. Topics in molecular quantum mechanics. At the level of Tinkham, *Group Theory and Quantum Mechanics*.

#### 596. STATISTICAL MECHANICS

Spring term. Credit four hours. Prerequisite: 593 or equivalent is desirable but not required.

Ensembles and partition functions. Thermodynamic properties of ideal gases and crystals. Third law of thermodynamics, equilibrium constants, vapor pressures, imperfect gases, and virial coefficients. Distribution and correlation functions. Lattice statistics and phase transitions. Bose-Einstein and Fermi-Dirac ideal gases. Maxwell theory of viscosity and heat conduction. At the level of T. L. Hill, *Statistical Thermodynamics*.

#### 598. SELECTED TOPICS IN PHYSICAL CHEMISTRY

Fall term. Credit two hours. Only grades of S or U will be given.

Detailed consideration is given to special topics selected from the field of theoretical and experimental physical chemistry. Topics are varied from year to year.

#### 600. GENERAL CHEMISTRY SEMINAR

Throughout the year. No credit. Only grades of S or U will be given.

A series of talks representative of all fields of current research interest in chemistry, given by advanced graduate students, research associates, faculty members, and distinguished visitors.

**601-602. INTRODUCTORY GRADUATE SEMINAR IN ANALYTICAL, INORGANIC, AND PHYSICAL CHEMISTRY**

Throughout the year. No credit. Required of all first-year graduate students majoring in chemistry and molecular biology. Only grades of S or U will be given.

Weekly seminars on contemporary topics prepared and presented by first-year graduate students. Attention given to details of selecting, preparing, and presenting a given topic. Group preparation and participation emphasized.

**650-651. GRADUATE SEMINAR IN ORGANIC CHEMISTRY**

Throughout the year. No credit. Required of all graduate students majoring in organic chemistry. Only grades of S or U will be given.

**700. BAKER LECTURES**

Fall term: Herbert C. Brown, Purdue University. Spring term: Lecturer to be announced.

**CIVIL ENGINEERING**

Faculty: Vaughn C. Behn (Sanitary); Donald J. Belcher (Aerial Photographs); George H. Blessis (Construction Engineering and Administration); Wilfried Brutsaert (Hydrology); Leonard B. Dworsky (Water Resources, Pollution Control); Melvin I. Esrig (Soils); Louis M. Falkson (Applied Welfare Economics); Gordon P. Fisher (Structures and Environmental Systems); Richard H. Gallagher (Structures); Charles D. Gates (Sanitary); Peter Gergely (Structures); David J. Henkel (Soils); William L. Hewitt (Subgrades, Pavements); Alonzo W. Lawrence (Sanitary); Taylor D. Lewis (Transportation); Ta Liang (Aerial Photographs, Physical Environment); James A. Liggett (Hydraulics); Raymond C. Loehr (Sanitary); Daniel P. Loucks (Water Resources Engineering); Walter R. Lynn (Environmental Systems); George B. Lyon (Surveying); William McGuire (Structures); Arthur J. McNair (Geodesy-Photogrammetry); Arthur H. Nilson (Structures); Charles S. ReVelle (Environmental Systems); Robert G. Sexsmith (Structures); Floyd O. Slate (Engineering Materials); Shaler Stidham, Jr. (Environmental Systems); Richard N. White (Structures); George Winter (Structures).

Visiting Professors: Paul Baron (Environmental Systems); Brian LeLievre (Soils); George Terzidis (Hydrology).

Field Representative: Arthur H. Nilson, 365 Hollister Hall.

**MAJOR SUBJECTS**

Aerial Photographic Studies\*  
(M.S. only)

Construction Management\*  
(M.S. only)

Environmental Systems  
Engineering

Geodetic and Photogrammetric  
Engineering

Geotechnical Engineering  
Hydraulics and Hydrology  
Sanitary Engineering  
Structural Engineering  
Transportation Engineering  
Water Resource Systems  
(Ph.D. only)

\* Concentration on Aerial Photographic Studies at the Ph.D. level is offered under the subject Geotechnical Engineering, and concentration on Construction Management at the Ph.D. level is offered under the subject Environmental Systems Engineering.

## MINOR SUBJECTS

All of the major subjects in the Field of Civil Engineering with the exception of Water Resource Systems can be taken as a minor subject. In addition, Structural Mechanics is an approved minor subject in the Field. All minor subjects may be used at both the M.S. and Ph.D. levels.

## PROFESSIONAL DEGREE

The School of Civil Engineering also offers the professional degree of Master of Engineering (Civil) which is intended primarily for those students who intend to enter engineering practice and who do not intend to obtain the doctorate. Work for this degree consists of courses which are designed to give the student a background in the elements of engineering design as well as a broad fundamental base. Those choosing the professional degree may concentrate their studies toward one or more of the sub-areas of civil engineering listed below or they may take a broad program without specific concentration.

**ADMISSION REQUIREMENTS.** To be admitted for graduate study in the Field of Civil Engineering, an applicant should hold a Bachelor's degree (or equivalent) in engineering, mathematics, or the sciences from a college of recognized standing. Though the Graduate Record Examination is not required in the Field of Civil Engineering, applicants are urged to take this examination, submitting its results along with their application for graduate work.

**LANGUAGE REQUIREMENTS.** There are no language requirements for the M.S. degree in Civil Engineering or M.Eng. (Civil) degree. The Ph.D. requires a reading knowledge of one foreign language, usually French, German, or Russian.

**EXAMINATIONS.** Civil Engineering requires a final comprehensive examination for the M.S. degree. For the Ph.D. degree the student must take (a) a qualifying examination shortly after receiving his M.S. or, if he comes to Cornell with an M.S., shortly after arrival; (b) a general examination on subject matter taken approximately at the time he completes his course work; and (c) a Final Examination in which the student is required to defend his dissertation.

**FINANCIAL AID.** Fellowships, traineeships, research assistantships, teaching fellowships, and laboratory assistantships are available to students seeking financial aid.

Additional information on specific programs is available by writing to the Field Representative, School of Civil Engineering. Study and research is usually carried on in one of the following areas:

## Courses and Research

### CIVIL ENGINEERING—GENERAL

#### 2001. THESIS

The thesis gives the student an opportunity to work out a special problem or to make an engineering investigation, to record the results of his work, and to obtain academic credit for such work. Registration for thesis must be approved by the professor in charge at the beginning of the semester during which the work is to be done.

Individual courses may be arranged to suit the requirements of graduate students. They are intended to be pursued under the immediate direction of the professor in charge, the student usually being free from the restriction of the classroom and working either independently or in conjunction with others taking the same course.

#### 2002. CIVIL ENGINEERING PRACTICE

Credit three hours. On demand. Prerequisite: fourth year or graduate standing.

Analysis of large engineering works; planning and organizing engineering and construction projects; professional practice; feasibility evaluations; financial justification of projects; social and political implications. The case method will be used extensively.

#### 2010. CIVIL ENGINEERING DESIGN PROJECT I

Fall term. Credit two hours. Normally required for students in the M.Eng. (Civil) Program. First term of a two-term sequence.

Design of a major civil engineering project embodying several aspects of civil engineering. Planning and part of preliminary design to be accomplished in the fall term. Remainder of preliminary design and final design in the spring term. Projects to be carried out by students working under the direction of a Faculty Project Coordinator.

#### 2011. CIVIL ENGINEERING DESIGN PROJECT II

Spring term. Credit three hours. Prerequisite: 2010. Normally required for students in the M.Eng. (Civil) Program.

Continuation of 2010.

### ENVIRONMENTAL SYSTEMS ENGINEERING

Environmental systems engineering is a unique area of activity, the main thrust of which is the application of systems analysis, operations research, and economics to the complex and massive technological problems of modern society which fall predominantly in the area of civil engineering. It is concerned with methods of allocation of resources in the public sector and with enhancement of the quality of information upon which to base rational decision-making and public investment. Particular emphasis is placed on transportation systems; air, water, and other natural systems; engineering and construction project management; solid waste disposal; and public health systems. There is special interest in the problems of urbanization, including an integrated approach to the many technological and planning aspects of modern urban areas, and to associated social and political factors.

Substantial effort is directed to the treatment of large-scale problems such as interurban and urban transportation networks, transport terminal facilities and intermodal transfer efficiency, river basin studies, rationalization of complex construction projects, optimal location of transportation links and public facilities and associated land use patterns and land values. The economics, planning, and management of all forms of man-made and natural environment, and the associated decision-making process are stressed. Much use is made of mathematical modeling and computers.

Through established relationships with the Departments of City and Regional Planning, Operations Research, Geotechnical Engineering, Structural Engineering, Water Resources Engineering, and many other areas of the University, students are encouraged to take advantage of a large variety of ancillary course offerings that support the general program of study.



Candidates for advanced degrees are considered who have undergraduate or graduate work in any area of civil engineering, in operations research/industrial engineering, and economics. Students with other backgrounds and well-developed career objectives will be considered for graduate studies.

### 301. MICROECONOMIC ANALYSIS

Fall term. Credit three hours. Lectures, M W F 10:10, plus discussion section. Prerequisite: one year of college-level mathematics.

Topics include the theory of the firm, production, market structures, consumer behavior, and welfare economics.

### 302. MACROECONOMIC ANALYSIS

Spring term. Credit three hours. Lectures, M W (F) 10:10, plus discussion section. Prerequisite: 301.

Topics include the theory of international trade, national income determination, economic growth and stability, and monetary and fiscal policy.

### 2601. TRANSPORTATION ENGINEERING

Fall term. Credit three hours. Two lectures, one laboratory.

Transportation systems analysis; traffic generation, distribution, and assignment models; modal split models. Elements of traffic flow theory and congestion. Physical environment evaluation, including route location and use of aerial photography. Transport economics. Technological and economic characteristics of current transportation modes. Current policy issues. Laboratory includes subgrade and pavement design, signalization methods and devices, geometric design and drainage. Under special circumstances, lectures may be scheduled for only two hours credit.

### 2602. LAW FOR ENGINEERS

Fall term. Credit three hours. Three lectures.

Basic features of laws and practices relating to contracts, torts, agency, property, water rights, business and government organizations, insurance, labor, governmental regulation of business, negotiable instruments, workmen's compensation, patents, ethical responsibilities of the engineer; term paper, comparative analysis of the legal principles which affected the court decisions in some actual cases. Legal structure and prerogatives of authorities and other regional agencies.

### 2604. CONSTRUCTION ENGINEERING

Fall term. Credit three hours. Three recitations.

Introduction to methods, equipment, and engineering principles and procedures involved in construction activities; major emphasis is on heavy construction such as large earth-moving projects, tunnels, caisson foundations, etc.

### 2611. ECONOMICS OF ENVIRONMENTAL QUALITY MANAGEMENT

Fall or spring term. Credit four hours. Prerequisite: 201 or equivalent.

A graduate seminar devoted to theoretical welfare economics and its application to the management of environmental quality.

### 2612. APPLIED WELFARE ECONOMICS

Credit one to four hours. On demand. Prerequisite: permission of the instructor.

This seminar is an extension of 2611 with substantially greater emphasis on the application of welfare economics, statistics, and systems analysis to public investment decisions in areas such as water resources, transportation and public health.

### 2617. ENVIRONMENTAL SYSTEMS ANALYSIS I

Fall term. Credit three hours. Three lectures. With permission of instructor. Intended for graduate students but open to qualified undergraduates.

Structuring and solution of mathematical programming models with emphasis on linear programming and its extensions. Introduction to Lagrangian multipliers, dynamic programming, nonlinear programming. Application of systems analysis techniques to the solution of complex environmental engineering-economic problems.

### 2618. ENVIRONMENTAL SYSTEMS ANALYSIS II

Spring term. Credit three hours. Three lectures. Prerequisite: IE 9320, 9522 or 9530 or permission of instructor.

Advanced topics in the application of mathematical programming and probability theory to the solution of environmental engineering problems. Special emphasis on topics such as water resource systems planning and management, transportation systems, public health systems, regional planning. Students will be expected to identify and solve practical problems using systems analysis.

### 2621. THEORY OF TRAFFIC FLOW

Fall term. Credit three hours. One meeting of two and one half hours per week. Prerequisite: IE 9170 or equivalent and consent of instructor.

Study of traffic flow phenomena and related mathematical models. Car-following models, hydrodynamic analogies, and other deterministic approaches. Probabilistic deductions, queuing models, Markov processes, simulation and other stochastic approaches. Flows in networks. Congestion and traffic assignment.

### 2622. TRANSPORTATION SYSTEMS ANALYSIS

Spring term. Credit three hours. Prerequisite: 301, 2621, IE 9360, and 2617 or IE 9522, or equivalents.

Techniques of systems analysis are applied to physical planning, operating, and financing of transportation facilities. Wherever applicable, mathematical models of transportation processes are used to examine questions related to the development of optimal public policy decisions in the area of transportation. Attention is given to analysis of single and multimodal forms of transportation. Methods of mathematical programming, simulation and stochastic processes are employed.

### 2626. TRAFFIC ENGINEERING

Fall term. Credit three hours. Two lectures, one laboratory. Prerequisite: permission of the instructor.

City and highway traffic surveys and designs. Accidents, congestion, delay, speed, volume, density, parking, channelization, lighting, traffic control, and routing. Signs, signals, and markings. Urban traffic consideration in city planning. Driver reaction and habit patterns. Traffic engineering organization.

### 2628. HIGHWAYS AND AIRPORTS—PLANNING AND DESIGN

Spring term. Credit three hours. Prerequisite: 2601 or permission of instructor.

Route selection; design controls and criteria, including vehicle characteristics and highway capacity; sight distance; horizontal and vertical control; right-of-way problems and access control; geometrics; at-grade intersection design; rotary and channelized intersection; grade separations and interchanges; regional systems of highways. Airport site selection; heliports; air traffic control. Terminal facilities.

**2631. CONSTRUCTION MANAGEMENT**

Spring term. Credit three hours. Prerequisite: permission of instructor.

Planning and operation of construction projects by the civil engineer using modern management techniques. Coordinated organization and control of men, materials, and machines; scheduling, estimating, purchasing, inventory, selection and training of employees, cost control, accident prevention.

**2632. CONSTRUCTION SYSTEMS ANALYSIS**

Spring term. Credit three hours. One three-hour meeting per week. Prerequisite: 2617 or consent of instructor.

A project-oriented seminar on the identification of important construction problems and the application to them of systems analysis, designed to give the student a deep experience in the formulation, conceptualization, and mathematical modeling of construction systems as a basis for rational decision making. Normally a single problem to be attacked is agreed upon by students and instructor. Typical problems have been (1) earth-moving and equipment scheduling on a major stretch of Interstate Highway 81, and (2) inventory control of construction projects.

**2691. ENVIRONMENTAL SYSTEMS DESIGN PROJECT**

Credit variable. On demand. Prerequisite: permission of the instructor. May extend over two semesters.

Design or feasibility study of environmental systems, supervised and assisted by one or more faculty advisors. Individual or group participation. Final report required.

**2692. ENVIRONMENTAL SYSTEMS ENGINEERING RESEARCH**

Credit variable. On demand. Prerequisite: preparation must be suitable to the investigation to be undertaken; permission of the instructor is required.

For investigation in depth of particular environmental systems problems.

**2693. ENVIRONMENTAL SYSTEMS ENGINEERING COLLOQUIUM**

Fall or spring term. Credit one to two hours. Required of all graduate students with a major or minor in Environmental Systems Engineering. Open to advanced undergraduates by permission of the instructor.

Preparation, presentation, and informal discussion of topics concerned with environmental systems. Distinguished outside lecturers.

**2694, 2695. SPECIAL TOPICS IN ENVIRONMENTAL SYSTEMS ENGINEERING**

Credit variable. On demand.

Supervised study by individuals or small groups in one or more specialized topics not covered in regular courses.

In addition to the above list, courses offered throughout the University may be selected to support studies in the general subject area of Environmental Systems Engineering. See especially other courses in Civil Engineering, City and Regional Planning (College of Architecture, Art, and Planning), Business and Public Administration, Economics (College of Arts and Sciences), and Operations Research (College of Engineering).

**GEOTECHNICAL ENGINEERING**

Geotechnical Engineering is concerned with the study of the engineering properties and use of earth materials and with the measurement of the earth

and its component parts. It includes soil and rock mechanics, foundation engineering, subgrades and pavements, studies of aerial photographs and other remote sensors, physical environment evaluation, surveying, geodesy and photogrammetry.

Graduate programs are designed to provide a sound theoretical and practical background in the various branches of the subject. The research interests of the faculty members cover a wide range of problems, and modern laboratory facilities are available to students for both teaching and research.

In soil mechanics and foundation engineering the current research is related to basic strength and deformation properties of soils that are under very low effective stresses. The mechanism of the development of landslides in stiff clays as well as in very soft underwater sediments are being studied. Particular attention is being given to the relationship between soil properties and the related topography. In geodesy, surveying, and photogrammetry, the research emphasis is on the development of photogrammetric methods for the measurement of the shape of large surfaces, such as that of the Arecibo Radio Astronomy Telescope, as well as of small surfaces such as of the human eyeball. The development of methodology for the measurement of earth movements is also being studied. Research is continuing in analytic aerotriangulation.

The work on aerial photographs and other remote sensing devices is concerned with inventory and evaluation of physical environment related to engineering, conservation, agriculture, geology, and regional planning. A large library of photographs from all over the world is available for study and research.

## SOIL MECHANICS AND FOUNDATION ENGINEERING

### 2406. FOUNDATION ENGINEERING

Spring term. Credit three hours. Three lectures. Prerequisite: 2401.

Principles of bearing capacity and deformation theory; stress distribution; shallow and deep foundations; prediction of settlement; design of footing, raft, caisson and pile foundations. Problems of construction, support of excavations; ground water lowering. Foundation investigations.

### 2410. ENGINEERING PROPERTIES OF SOILS

Fall term. Credit three hours. Three lectures. Prerequisite: 2401.

The natural environments in which soils are formed; the chemical and physical nature of soils; soil classification; the principle of effective stress; shear strength and compressibility of saturated and partly saturated soils; sensitivity; effects of anisotropic consolidation; permeability; laboratory and field tests.

### 2412. GRADUATE SOIL MECHANICS LABORATORY

Spring term. Credit three hours. Prerequisite: 2410.

The laboratory measurement of soil properties: classification tests; direct shear tests; triaxial tests for the measurement of pore water pressure; strength parameters. Pore pressure dissipation tests. Relationship of laboratory tests to field behavior.

### 2414. EARTH PRESSURE AND SEEPAGE

Fall term. Credit three hours. Three lectures. Prerequisite: 2401.

The mechanics of the development of earth pressure in relation to soil properties and the imposed deformation conditions. The effects of seepage on the development of earth pressure. Design and stability of bulkheads

and cofferdams. Pressures on shafts, tunnels and conduits. The steady and transient flow of fluids through compressible and incompressible porous media. Consolidation processes. Sand drains. Field determination of permeability. Flow nets and the modification of flow patterns by drains and relief wells.

#### 2416. SLOPE STABILITY, EARTH AND ROCK-FILL DAMS

Spring term. Credit three hours. Three lectures. Prerequisite: 2401.

Principles of stability for earth and rock slopes; effects of pore water pressure; short and long term stability; problems of draw-down; analysis of landslides and dam stability; principles of earth and rock-fill dam design; internal pore water pressures and drainage; filters; relief wells; foundation problems; grouting; cut-offs; control and instrumentation.

#### 2418. CASE STUDIES IN SOIL MECHANICS AND FOUNDATION ENGINEERING

Spring term. Credit three hours.

The study of real engineering problems of various types; the importance of the geological environment in recognizing the nature of field problems; the application of mechanics and soil properties to obtain engineering solutions. The preparation of engineering reports.

### AERIAL PHOTOGRAPHIC STUDIES, PHYSICAL ENVIRONMENT EVALUATION, AND SUBGRADES AND PAVEMENTS

#### 2421. PHYSICAL ENVIRONMENT EVALUATION

Fall term. Credit three hours. Two lectures, one laboratory. Intended for graduate students or upperclassmen in engineering and planning. Permission of the instructor is required.

A study of physical environment factors affecting engineering and planning decisions and the evaluation methods of these factors. Physical factors include the climate, soil and rock conditions, and water resources in different parts of the world. Evaluation methods include field reconnaissance, interpretation of meteorological, topographic, geological, and soil maps, aerial photography, engineering data, and sub-surface exploration records.

#### 2422. ADVANCED PHYSICAL ENVIRONMENT EVALUATION

Spring term. Credit three hours. Two lectures, one laboratory. Intended for graduate students or upperclassmen in engineering or planning. Prerequisite: 2421 or 2423 or permission of the instructor.

A study of physical environment by use of airphotos and other remote-sensing methods. Conventional photography, sequential photography, multiple spectral photography, space photography, infrared thermal and radar images are included in the study. Evaluation of environment is directed to the planning of engineering and development projects in general, and some emphasis on those related to special climatic regions such as tropical humid as well as arid regions.

#### 2423. ANALYSES AND INTERPRETATION OF AERIAL PHOTOGRAPHS

Fall and spring terms. Credit three hours. Two lectures, one laboratory. (The student is expected to pay the cost of field trips and aerial photographs for use in a term project, amounting to approximately \$15.)

Course presents methods of identification of a broad spectrum of soils, rocks,

and drainage conditions as well as the significance of vegetative and cultural patterns of the world. Natural resources inventories and specific fields of application are emphasized.

#### 2424. ADVANCED INTERPRETATION OF AERIAL PHOTOGRAPHS

Fall and spring terms. Credit three hours. Preregistration required.

Course includes lectures and team projects in laboratory and field. Facilities include material for city-regional planning, soil mapping, conservation, ground and surface water, and civil engineering projects.

#### 2431. SUBGRADES AND PAVEMENTS FOR HIGHWAY AND AIRPORTS

Offered upon sufficient demand, usually in spring term. Credit three hours. Two lectures, one laboratory. Prerequisite: 2601 or permission of the instructor.

Part I: Subgrade evaluation; compaction; drainage and frost action; stabilization. Part II: Aggregates; bituminous materials; evaluation of flexible pavement components; design and construction of flexible pavement structure. Part III: Design and construction of rigid pavements.

#### 2432. LOW-COST ROADS

Offered upon sufficient demand, usually in fall term. Credit three hours. Primarily for foreign students. Prerequisite: consent of the instructor. Principally directed study with a two-and-a-half-hour class session per week.

Rural road systems as instruments of economic development. Study of economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

### GEODETTIC AND PHOTOGRAMMETRIC ENGINEERING

#### 2452. ELEMENTS OF SURVEYING

Fall and spring terms. Credit two hours. One lecture, one laboratory.

Fundamentals of engineering measurements. Study of observations and errors. Principles of recording data. Use of steel tape, level, and transit. Optical tooling. Photogrammetry. Problems of particular interest to students in fields other than civil engineering.

#### 2461. ELEMENTARY GEODESY

Fall term. Credit three hours. Three lectures.

Principal problems of geodesy. Coordinate systems, reference datum. Geometric problems on earth ellipsoid. Geometric astronomy. Application of Bjerhammar singular matrix calculus; singular matrices to geodesy.

#### 2462. GEOPHYSICAL GEODESY

Spring term. Credit three hours. Three lectures.

Basic potential theory, Laplace and Poisson equations; gravity and potential field in, on, and outside the spheroid; figure of the earth, application of Stokes formula for determining undulations of the geoid and deflection of the vertical; applications of spherical harmonics.

#### 2463. GEODETTIC CONTROL SURVEYS

On demand. Credit three hours. Two lectures, one laboratory. Prerequisite: 2451 or 2461.

Principles of establishing a geodetic sea-level datum; isostasy, the geoid and ellipsoid; altimetry, trigonometric, spirit, and electronic leveling; orthometric and dynamic heights; electronic distance measurement; triangulation and trilateration; design of control networks and systems; astronomic and gravimetric observations, and satellite triangulation.

#### 2464. GEODETIC ASTRONOMY

On demand. Credit two hours. Two lectures. Prerequisite: 2451 or equivalent work in field astronomy.

Study of the precise determination of latitude, longitude, and azimuth from astronomical observations. Night observation periods.

#### 2465. ADVANCED ENGINEERING MEASUREMENTS

Fall term. Credit three hours. Prerequisites: laboratory work involving physical measurements, Math 293 or equivalent.

Measurement systems; analysis of errors and of error propagation; application of the principles of probability to the results of measurements for the purpose of determining the best estimates of measured and deduced quantities; and the best estimate of uncertainty in these quantities; adjustment of conditioned measurements by the method of least squares and other methods; and curve fitting.

#### 2466. MAP PROJECTIONS AND CARTOGRAPHY

Credit three hours. Three lectures. On demand.

Theory of map projections including conformal, equal-area, azimuthal equidistant, et al., projections; coordinate transformations; plane coordinate systems for surveying. Design of map projections. Cartographic principles, systems, and related economic factors.

#### 2471. ELEMENTS OF PHOTOGRAMMETRY

Fall term. Credit three hours. Lecture, laboratory.

Principles and practice of terrestrial and aerial photogrammetric mapping, including planning flights, control surveys, uncontrolled mosaics, radialline control, simple stereoplotting instruments, parallax distortions, graphical tilt determination, trimetrogen charting, and economics. A Balplex projection stereoplotter with three projectors is available for use.

#### 2472. ADVANCED PHOTOGRAMMETRY

Spring term. Credit three hours. Two lectures, one laboratory. Prerequisite: 2471.

An advanced study of photogrammetric principles including: controlled mosaics; rectification; graphical and instrumental aerotriangulation. Principles of photogrammetric plotters and systems and the economic relation of these to density of ground control, office methods, and personnel. Balplex projection plotter is used extensively.

#### 2473. ANALYTICAL AEROTRIANGULATION

On demand. Credit three hours. Three lectures. Prerequisite: 2471.

Analysis, theories, and computation of stereostrip triangulation by direction cosines, vector, and matrix methods. Coplanarity and colinearity equations for relative orientation and absolute orientation. Stereogram assemblage and coordinate transformation of strip and block coordinates. Cantilever extension and general bridging solutions. Propagation of errors.

**2481. CADASTRAL SURVEYING**

On demand. Credit three hours. Three lectures.

Study of legal principles and surveying operations associated with acquisition of evidence for the delineation of boundaries of real estate. Topics covered include: metes and bounds, subdivision, and other methods of description of real property; land courts; riparian rights; mineral rights; resurveys; and authority and responsibilities of the Cadastral surveyor.

**2482. ENGINEERING SURVEYS**

Spring term. Credit three hours. One lecture, two laboratories. Prerequisite: 2451 or equivalent.

Circular curves, transition curves, earthwork measurement and calculation, topographic surveys, construction surveys, and project planning from maps.

**2491. GENERAL DESIGN PROJECT IN GEOTECHNICAL ENGINEERING**

Credit one to six hours. On demand.

Design problems frequently associated with the Master of Engineering Program.

**2492. RESEARCH IN GEOTECHNICAL ENGINEERING**

Credit one to six hours. On demand. For students who wish to study one particular area of geotechnical engineering in depth.

The work may take the form of a laboratory investigation, field study, theoretical analyses or the development of design procedures.

**2493. SEMINAR IN GEOTECHNICAL ENGINEERING**

Fall and spring terms. Credit one to two hours.

Presentation and discussion of technical papers and current research in the general field of geotechnical engineering or one of its specialized fields.

**2494. SPECIAL TOPICS IN GEOTECHNICAL ENGINEERING**

Credit one to six hours. On demand.

Supervised study in small groups in one or more special topics not covered in the regular courses. Special topics may be of a theoretical or applied nature.

**2495. FIELD PRACTICE IN GEOTECHNICAL ENGINEERING**

Credit three hours. Extends throughout the academic year with field studies conducted as two-day trips allocated to appropriate weekends in each term. The student is expected to pay transportation and related costs, amounting to approximately a total of \$85. Prerequisite: 2401 or permission of the instructor.

Designed to provide experience with field conditions in important project environments within reach of the campus, including construction scenes in New York and central Pennsylvania. Preparation for and reports on various sites is a requirement.

The program includes field testing and sampling; resistivity and seismic probing of soils and bedrock; soil moisture and density measurements using nuclear equipment. Engineering construction practices and site evaluation related to landslides, bedrock, drainage, and unstable soils. The influence of rock types, ground water, and soil materials on existing structures; appropriate design procedures applied to sophisticated structures at difficult sites.

## **STRUCTURAL ENGINEERING**

Structural engineering embraces not only the more conventional aspects of civil engineering design but also other structural work, such as aeronautical



and space structures, nuclear engineering structures, tanks, bins, pressure vessels, antenna towers, and the like. Emphasis is placed on the common fundamental background, theoretical and experimental, of all structural engineering. Structural and materials behavior being inseparably related, instruction and research in the field of structural materials is regarded as part of the area of structural engineering.

Complete facilities for experimental structural research of all kinds are available including a structural testing hall fifty feet by eighty feet in plan, and forty-five feet high for full-scale three-dimensional static and fatigue testing of structures; static- and fatigue-testing machines of a variety of capacities; appropriate measuring equipment; a versatile and fully equipped structural models laboratory; and a large laboratory for concrete and other cementitious materials.

The facilities of the University computing center, including the IBM 360-65 are available for use by graduate students in course work and research.

The department has a large number of externally and internally sponsored research projects upon which students can base theses and receive research assistantships. The externally sponsored projects include: shell structures of light gage steel, microcracking of concrete and its influence on structural behavior and fracture, behavior of beams and columns braced by diaphragms, performance of stainless steel structural members, torsional-flexural buckling of eccentrically loaded columns, fundamental concepts of cracking phenomena in reinforced concrete structures, effects of cold forming on performance of light gage steel members, influence of ductility on structural behavior, cable suspended roof structures, anchorage systems in prestressed concrete reactor vessels, reinforced concrete models, and structural reliability.

A separate brochure on *Structural Engineering at Cornell University* is available on request from the School of Civil Engineering, Hollister Hall.

## 2710. STRENGTH OF STRUCTURES

Fall term. Credit three hours. Three recitations. Prerequisite: 2703; can be taken concurrently.

Analysis of two- and three-dimensional stress and strain. Theories of failure of ductile and brittle materials. Microstructure of materials. Structural materials under load, strain hardening, Bauschinger effect, residual stresses, hysteresis, stress concentration, brittle fracture, creep, alternating stress. Design for fatigue. Stresses beyond the elastic limit. Inelastic behavior of steel and reinforced concrete structures. Critical discussion of recent research and current design specifications.

## 2711. BUCKLING: ELASTIC AND INELASTIC

Spring term. Credit three hours. Prerequisite: 2710.

Analysis of elastic and plastic stability. Determination of buckling loads and postbuckling behavior of columns. Solid and open web columns with variable cross-section. Beam columns. Frame buckling. Torsional-flexural buckling. Lateral strength of unbraced beams. Buckling loads and post-buckling behavior of plates, shear webs, and cylindrical shells. Critical discussion of current design specification.

## 2712. ADVANCED STRUCTURAL ANALYSIS

Fall and spring terms. Credit three hours. Three lectures. Prerequisites: 2703 or consent of instructor; concurrent registration in CS 311.

Stability, determinacy, redundancy of structures. Approximate methods of analysis. Force, displacement, and transfer matrix methods of matrix structural analysis. Development of space frame element equations, including distributed

loads and thermal strain effects. Methods of solution: direct and iterative, tridiagonalization, partitioning, and special transformations. Analysis techniques for tall buildings and other special problems.

#### 2713. FINITE ELEMENT ANALYSIS

Spring term. Credit three hours. Three lectures. Prerequisite: 2712.

Theoretical and conceptual bases for formulation of finite element representations in continuum mechanics. Development of element relationships for structural analysis of plates, shells, and solids. Extension of element and system solution techniques to deal with problems in elastic stability, inelastic deformation, finite displacements, dynamic response, and other special behavior mechanisms.

#### 2714. STRUCTURAL MODEL ANALYSIS AND EXPERIMENTAL METHODS

Spring term. Credit three hours. Two lectures, one two-hour period. Prerequisite: indeterminate analysis.

Dimensional analysis and principles of similitude. Indirect model analysis of beams, frames, and trusses. Direct model analysis including loading and instrumentation techniques. Strain measurement and interpretation. Confidence levels of model results. Laboratory projects in elastic behavior and ultimate strength of model structures.

#### 2715. NUMERICAL METHODS AND PROBABILITY

Fall term. Credit three hours. Prerequisites: differential equations and consent of instructor; concurrent registration in CS 311.

Numerical integration techniques. Solution of linear systems. Finite difference techniques for boundary value problems. Eigenvalue determination. Introduction to probability concepts pertaining to structural analysis and design. Structural reliability; inference techniques; decision theory; stochastic processes.

#### 2716. CONCRETE STRUCTURES I

Fall term. Credit three hours. Three lectures per week. Prerequisite: 2703 or equivalent.

Analysis, design, and behavior of prestressed concrete structures; beams, slabs, composite construction, continuous beams and frames, tension and compression members; deflection analysis, end zone stresses, detailing, losses, efficiency. Design of concrete shells: shells of revolution, hyperbolic paraboloids.

#### 2717. CONCRETE STRUCTURES II

Spring term. Credit three hours. Three lectures per week. Prerequisite: 2703 or equivalent.

Analysis, design and behavior of reinforced concrete structures; safety considerations, deflection analysis, crack control; beams, columns, slabs, continuous frames, flat plates, flat slabs, composite construction; limit analysis and yield line theory; design of concrete shells: folded plates and cylindrical shells.

#### 2718, 2719. BEHAVIOR AND DESIGN OF METAL STRUCTURES

Fall and spring terms. Credit three hours each term. Prerequisite: 2703 or equivalent.

Contemporary methods for analyzing and designing metal structures. Behavior of structural elements and frames. Selected design applications from the fields of steel plate structures, bridges, suspension systems, light weight structures.

**2720. SHELL THEORY AND DESIGN**

Fall term. Credit three hours. Prerequisites: Math 294 or equivalent and consent of the instructor.

Differential geometry of surfaces. Bending and membrane theory of shells. Analysis and design of cylindrical shells, domes, paraboloids. Application to reinforced concrete roofs and pressure vessels. Stability of certain types of shells.

**2722. DYNAMICS OF STRUCTURES**

Spring term. Credit three hours. Prerequisites: Math 294 or equivalent and consent of the instructor.

Equations of motion and vibration of simple systems. Numerical, energy and matrix methods of analysis of multiple degree systems. Analysis and design of structures for ground disturbances, including inelastic effects.

**2730. AEROSPACE STRUCTURAL ANALYSIS**

Fall term. Credit three hours. Prerequisites: Mechanics 211 and 212.

Evolution of aerospace structural design concepts and the design cycle. Structural design criteria, environments, and specifications. Materials of construction and their properties. Modes of failure. Review of analytical problem areas, including dynamic response, aeroelasticity and thermal protection. Design charts for stressed skin construction.

**2752. ADVANCED PLAIN CONCRETE**

Spring term. Credit two hours. Two lectures. Prerequisite: 2751 or the equivalent.

Topics in the field of concrete, such as history of cementing materials, air-entrainment, light weight aggregates, petrography, durability, chemical reactions, and properties of aggregates. Relationships between internal structure, physical properties, chemical properties, and the mechanical properties of interest to the design and construction engineer.

**2753. STRUCTURE AND PROPERTIES OF MATERIALS**

Fall term. Credit three hours. Two lectures plus conference. Open to graduate students in engineering or the physical sciences, or to undergraduates by consent of the instructor.

Internal structure of materials ranging from the amorphous to the crystalline state. Forces holding matter together versus forces causing deformation and failure. Correlation of the internal structures of materials with their physical and mechanical properties. Applications to various engineering materials.

**2757. CIVIL ENGINEERING MATERIALS PROJECT**

On demand. Credit one to six hours.

Individual projects involving civil engineering materials.

**2758. CIVIL ENGINEERING MATERIALS RESEARCH**

On demand. Hours and credit variable.

Individual assignments, investigations and/or experiments with civil engineering materials.

**2791. DESIGN PROJECT IN STRUCTURAL ENGINEERING**

(Meets project requirement for M.E. degree.) Credit: fall, one hour; spring, three hours; both terms required.

Comprehensive design projects by design teams. Formulation of alternate de-

sign proposals, including economics and planning, for a given situation and complete design of the best alternate. Determination of construction costs and preparation of sketches and drawings. Presentation of designs by oral and written reports.

#### 2792. RESEARCH IN STRUCTURAL ENGINEERING

On demand. Hours and credit variable. Students wishing to pursue one particular branch of structural engineering further than can be done in any of the regular courses may elect work in this field. The prerequisite courses depend upon the nature of the work desired.

The work may be in the nature of an investigation of existing types of construction, theoretical work with a view of simplifying present methods of design or proposing new methods, or experimental investigation of suitable problems.

#### 2793. STRUCTURAL ENGINEERING SEMINAR

Spring term. Credit one to three hours. Open to qualified seniors and graduate students. Preparation and presentation of topics of current interest in the field of structures for informal discussion.

#### 2794. SPECIAL TOPICS IN STRUCTURAL ENGINEERING

On demand. Hours and credit variable.

Individually supervised study in one or more of the specialized topics of civil engineering such as tanks and bins, suspension bridges, towers or movable bridges, which are not covered in the regular courses. Independent design or research projects may also be selected.

### HYDRAULICS AND HYDROLOGY

Two modern laboratories make possible a wide range of instructional and research experimentation. In the Hollister Hall applied fluid mechanics laboratory, well-instrumented models support experimental studies in all phases of fluid flow. At the Applied Hydraulics Laboratory near Beebe Lake, flows up to fifty cubic feet per second and natural heads up to eighty feet are available for both research and testing.

Current staff research in hydraulics and hydrology include studies in lake circulation; secondary currents in non-circular conduits; mathematical models of hydrologic systems; non-linear storage routing methods; drainage from large unconfined aquifers; recovery of infiltration capacity in soils with hysteresis; permeability models for porous materials; time series analysis of lake evaporation; random structure of drought flows; physics of lake and pan evaporation; heat transfer from lakes.

#### 2303. HYDROLOGY

Fall term. Credit two hours. Two lecture-recitations. Prerequisite: 2301.

Introduction to hydrology including topics on precipitation, evapotranspiration, ground water, surface water, sedimentation.

#### 2312. EXPERIMENTAL AND NUMERICAL METHODS IN FLUID MECHANICS

Fall and spring terms. Credit two hours. Prerequisite: 2302 or permission of the instructor. Primarily a laboratory course for undergraduates and graduates; may be repeated for credit on permission of the instructor.

Emphasis is on planning and conducting laboratory and field experiments and on numerical computation. Each section is limited to four students.

**2315. ADVANCED FLUID MECHANICS I**

Fall term. Credit three hours. Three recitations. Prerequisite: 2301

Introduction to vector and tensor notation. The equations of conservation of mass, momentum, and energy from a rigorous point of view. Similitude and modeling potential flow including circulation, vorticity, conformal mapping, and hodograph methods.

**2316. ADVANCED FLUID MECHANICS II**

Spring term. Credit three hours. Three recitations. Prerequisite: 2315.

Exact solutions to the Navier-Stokes equations, the laminar and turbulent boundary layers, turbulence, introduction to non-Newtonian flow, and other topics.

**2317. FREE SURFACE FLOW**

Spring term. Credit three hours. Three recitations. Prerequisite: 2315 or permission of the instructor.

The formulation of the free surface equations and boundary conditions. Shallow water theory and the theory of characteristics. Unsteady and two-dimensional flow in open channels. Theory of small amplitude waves.

**2320. SURFACE-WATER HYDROLOGY**

Fall term. Credit three hours. Prerequisite: 2301.

Physical and statistical analysis relating to hydrologic processes. Hydro-meteorology and evaporation. Surface runoff, base flow and storage routing in linear and nonlinear systems. Unit hydrograph theory.

**2321. FLOW IN POROUS MEDIA**

Spring term. Credit three hours. Prerequisite: 2301 (also recommended, 2315).

Fluid mechanics of flow through porous solids. The general equations of single phase and multiphase flow and the methods of solving the differential form of these equations. Hydraulics of wells, of infiltration and of ground water recharge, and of other steady state and transient seepage problems in fully and partially saturated materials.

**2331. RIVER AND COASTAL HYDRAULICS**

Spring term. Credit three hours. Prerequisite: 2302 or permission of the instructor.

First part deals with the hydraulics of fixed bed channels including the specific energy concept, secondary currents, rapid flow problems, artificial obstructions in channels, and the general problem of frictional resistance. In the second part, attention is paid to coastal and oceanographical engineering problems including the theory of waves, breaking of waves, wave refraction and wave diffraction.

**2332. SEDIMENT TRANSPORT**

Fall term. Credit three hours. Prerequisite: 2302 or permission of the instructor.

Hydraulics of channels with a movable bed including particle mechanics, critical tractive force theory, the DuBoys Problem, the Swiss formulas, Einstein's Bedload theory, the suspension and saltation theory, and calculation of total sediment loads. Interesting problems in fluvial hydraulics will be included.

**2391. PROJECT**

Offered on demand. Hours and credit variable.

The student may elect a design problem or undertake the design and construction of special equipment in the fields of fluid mechanics, hydraulic engineering or hydrology.

**2392. RESEARCH IN HYDRAULICS**

Offered on demand. Hours and credit variable.

The student may select an area of investigation in fluid mechanics, hydraulic engineering, or hydrology. The work may be either of an experimental or theoretical nature. Results should be submitted to the instructor in charge in the form of a research report.

**2393. HYDRAULICS SEMINAR**

Fall and spring terms. Credit one hour. Open to undergraduates and graduates and required of graduate students majoring in hydraulics or hydraulic engineering.

Topics of current interest in fluid mechanics, hydraulic engineering, and hydrology.

**2394. SPECIAL TOPICS IN HYDRAULICS**

Offered on demand. Hours and credit variable.

Special topics in fluid mechanics, hydraulic engineering, or hydrology.

**SANITARY ENGINEERING AND WATER RESOURCE SYSTEMS ENGINEERING**

Graduate study and research in sanitary engineering is concerned with the development of fundamental knowledge of pertinent physical, chemical, and biological phenomena and principles. This knowledge, along with skills in applied mathematics, statistics, and probability, is used in the analysis and design of processes, structures and systems for water quality control, water quantity control, and waste management. Advanced study in water resource systems offers an opportunity to develop and combine competence in water quality technology, hydraulics, hydrology, economic theory, and operations research, and to apply this knowledge to the solution of engineering problems in water resources planning and management. The sanitary engineering facilities contain some 6,300 square feet of laboratory space and controlled temperature rooms and include separate specially equipped laboratories for water bacteriology and biology, water chemistry, bench and pilot-level unit process studies, and radiological measurements.

Students and staff are currently collaborating in such diverse research areas as kinetics of biological waste treatment processes; mathematical formulation of biological oxidation kinetics; nutrient cycles and reactions in receiving waters; solid wastes management; treatment and disposal of industrial wastes; mathematical decision models for water quality control; optimization of water and waste treatment process design and plant operation; mathematical decision models for the operation of water resource systems; and water pollution control policies.

**2502. WATER AND WASTE-WATER TREATMENT PROCESSES**

Spring term. Credit three hours. Two lectures, one laboratory. Prerequisite: 2301.

Study of the microbiological, chemical, and physical phenomena and proc-

esses underlying the treatment of water and of municipal and industrial wastewater. Laboratory studies of water quality and of unit treatment processes.

#### 2510. CHEMISTRY OF WATER AND WASTE WATER

Fall term. Credit three hours. Two lecture, recitations, one laboratory. Prerequisite: one year of college chemistry.

Principles of chemistry applicable to the understanding, design, and control of water and waste-water treatment processes and to reactions in receiving waters. Analytical methods applicable to the measurement and control of air and water quality.

#### 2512. MICROBIOLOGY OF WATER AND WASTE-WATER

Spring term. Credit three hours. Two lectures, one laboratory.

Introduction to the characteristics of microorganisms, their interaction with the environment, and their effect on water quality. Their role in the oxidation of organic substances in waste-water treatment and in receiving waters. Kinetics of microbial substrate assimilation and growth. Bacteriological, biological, and limnological parameters of water quality and their measurement.

#### 2513. TREATMENT PROCESSES

Fall term. Credit three hours. Three lectures. Prerequisite: 2502 or equivalent.

Analysis and design of processes for the removal of impurities from water and from municipal and industrial waste water. Theoretical and applied aspects of treatment process design, including reaction kinetics, transfer phenomena, and the mechanics of fine particles.

#### 2514. ASSIMILATION OF WASTES IN WATER

Spring term. Credit three hours. Three lectures. Prerequisite: appropriate undergraduate course.

Capacity of water resources to assimilate gaseous, liquid, and particulate wastes. Phenomena pertinent to the dispersion and stabilization of wastes in water. Analog and digital computer methods. Emphasis on the advanced literature.

#### 2515. WATER RESOURCES PROBLEMS AND POLICIES

Fall term. Credit three hours. Lecture-discussion. Prerequisite: permission of the instructor. Intended primarily for graduate engineering and nonengineering students but open to qualified undergraduates.

A comprehensive approach to water resources planning and development. Historical and contemporary perspectives of water resources problems, organization, and policies.

#### 2518. WATER RESOURCE SYSTEMS

Spring term. Credit three hours. Prerequisites: Economics 301; 2617 or 9522; 9360 or 9460 or permission of instructor.

Application of economic theory and systems analysis to problems in water resources planning and management. Deterministic and stochastic models. Review of current literature.

#### 2520. ENVIRONMENTAL HEALTH ENGINEERING

Spring term. Credit three hours. Three lectures, reports. Prerequisite: 2501 or equivalent or permission of the instructor.

Concepts of environmental health, principles of epidemiology and of toxicology.

## 102 CIVIL ENGINEERING

cology. Introduction to radiological health. Consideration of problems in environmental control with emphasis on waste management, water quality control, air quality control, and solid waste disposal.

### 2530. SOLID WASTE MANAGEMENT

Spring term. Credit three hours. Lecture, reports. Prerequisite: permission of the instructor.

Study of municipal, industrial, and agricultural solid waste. Emphasis on waste characteristics, methods of treatment and disposal, and interrelationships with the air, water, and land environment. Intended primarily for graduate students but open to qualified undergraduates.

### 2532. ENVIRONMENTAL QUALITY ENGINEERING

Fall term. Credit three hours. Open to other than civil engineering students. Lecture-discussion, reports, and field trips.

Environmental health concepts and their application to environmental quality control at the subdivision, municipal, and metropolitan levels. Introduction to water resource planning and development; water quality control; water supply; municipal, industrial, and private waste-water disposal; air quality control; solid waste disposal and radiological health.

### 2545. WATER RESOURCES PLANNING SEMINAR

Spring term. Credit three hours. Prerequisite: 2515 or permission of the instructor.

The concepts, processes, and techniques of regional, multi-purpose river basin planning and development. The case study method, including the preparation of an integrated, comprehensive report for the study area, is followed.

### 2547. SEMINAR IN WATER RESOURCES SYSTEMS ANALYSIS

Spring or fall term. Credit four hours. Prerequisite: permission of the instructor which will be based on the student's ability to contribute substantially to the seminar.

An interdisciplinary approach to the solution of a complex problem in water resources engineering involving the application of systems analysis, statistics, economic theory, hydrology, and hydraulic and sanitary engineering. Each student will study and discuss a particular aspect of the problem. The results of the individual studies should contribute to the solution of the overall problem.

### 2591. DESIGN PROJECT

On demand. Credit variable. Prerequisite: 2501 or 2502 or equivalent.

The student will elect or be assigned problems in the design of water and waste-water treatment processes or plants; waste-water disposal systems; water quality control systems; water resource development or management systems; or of laboratory apparatus of special interest.

### 2592. SANITARY ENGINEERING RESEARCH

On demand. Credit variable. Prerequisites will depend upon the particular investigation to be undertaken.

For the student who wishes to study a special topic or problem in greater depth than is possible in formal courses.



**2593. SANITARY ENGINEERING COLLOQUIUM**

Fall and spring terms. Credit one to two hours. Required of all graduate students taking a major or minor in sanitary engineering; open to undergraduates by permission of the instructor.

Preparation, presentation, and discussion of topics and problems of current interest in sanitary engineering and water resources engineering.

**2594. SPECIAL TOPICS IN SANITARY AND WATER RESOURCE SYSTEMS ENGINEERING**

Offered on demand. Hours and credit variable.

Supervised study in special topics not covered in formal courses.

**COMPUTER SCIENCE**

Faculty: H. D. Block, James H. Bramble, Kenneth M. Brown, Robert L. Constable, Richard W. Conway, Juris Hartmanis, John E. Hopcroft, William L. Maxwell, Charles W. Merriam, Howard L. Morgan, Anil Nerode, Christopher Pottle, Gerard Salton, Sidney Saltzman, Shayle R. Searle, Alan C. Shaw, Roland A. Sweet, Robert J. Walker, Peter Wegner.

Field Representative: John E. Hopcroft, Upson Hall.

**MAJOR AND MINOR SUBJECTS**

Computer Science  
Information Processing

Numerical Analysis  
Theory of Computation

**ADMISSION REQUIREMENTS:** As prerequisite for admission in this Field, a student is expected to have had significant experience in programming a digital computer, and, depending upon the particular subject major chosen, appropriate background in mathematics, engineering, linguistics, etc., to permit the immediate enrollment in graduate level courses. A student is also expected to have had at least an introductory course in computer science although this deficiency can be remedied after admission.

**FOREIGN LANGUAGE REQUIREMENTS:** A candidate for the degree of Ph.D. must demonstrate reading ability in two approved languages besides English. Approved languages are French, German, Russian, and any language in which there exists a substantial body of literature in the area of the student's doctoral thesis. There is no Field requirement of a foreign language for the M.S. degree.

Any Special Committee may, at its discretion, require knowledge of foreign language beyond the above requirements.

**OTHER FIELD REQUIREMENTS:** All candidates for the Ph.D. are required to have at least one minor in a field other than computer science. The most frequent choices would be in the Fields of Mathematics, Applied Mathematics, Statistics, Operations Research, Electrical Engineering, Ecology and Evolutionary Biology, Psychology, or Linguistics, but others would be possible.

Examinations required by the Graduate School are described on page 12 of this *Announcement*.

One semester of part-time teaching experience is required for the Ph.D. degree.

## General Comments

The Field of Computer Science at Cornell includes not only the fundamental theoretical material in automata, computability, and language structure but also such subjects as numerical analysis and information processing, which underlie broad areas of computer application. A graduate student should consider a major in computer science if he is primarily interested in the general aspects of computational processes, both theoretical and practical, e.g., theory of algorithms, methods by which algorithms are implemented on a computer, and information structures. If he is primarily interested in the results of a computer process and its relation to a particular area of application, then he should major in another field and consider a minor in computer science.

## Research and Study Opportunities

Opportunities exist for research and study in the following areas of computer science: numerical analysis (Bramble, Brown, Sweet, Walker), programming languages and systems (Conway, Maxwell, Morgan, Saltzman, Shaw, Wegner), automata and computability theory (Constable, Hartmanis, Hopcroft, Nerode), information organization and retrieval (Salton), systems and control theory (Merriam, Pottle), adaptive systems (Block).

## Computing Facilities

The principal computing facility at Cornell is an IBM 360 Model 65. This is located in Langmuir Laboratory at the Cornell Research Park on the periphery of the campus, and is directly linked to satellite computers at three different campus locations. The Engineering College and the Department of Computer Science are served through one of these satellite stations in Upson Hall as well as by a number of teletypewriter terminals in different locations. An IBM 1800 computer is also linked to the central computer to provide an analog-digital interface and graphical display equipment.

A booklet describing in more detail the graduate work in Computer Science and closely related subjects at Cornell can be obtained by writing to the Field Representative, Upson Hall.

## Courses

### 385. AUTOMATA

Spring term. Credit three hours. Prerequisite: Mathematics 294 or 222 or equivalent. M W F 10:10.

The capabilities, limitations and structures of finite automata, turing machines and other abstract computing devices will be studied. Applications to questions of undecidability and artificial intelligence.

### 401. COMPUTER ORGANIZATION AND PROGRAMMING

Either term. Credit four hours. Prerequisite: Mathematics 221 or 293 or equivalent. T Th 11:15, W 2:30-4:25.

Characteristics and structure of digital computers. Programming in assembly and higher-order languages. Representation of data, index registers and

indirect addressing, program organization, macro operations, recursive procedures, interpretive routines, auxiliary storage and input-output, operating systems.

#### 404. ADVANCED COMPUTER PROGRAMMING

Spring term. Credit four hours. Prerequisite: 401 or consent of instructor. T Th 1:25, F 2:30.

This course is intended for students who wish to learn computer programming for eventual use in professional systems programming or advanced applications. To develop this ability, the basic logical and physical structure of digital computers is considered and the applicability and limitations of this structure are studied through many examples and exercises. The approach, therefore, is not a theoretical one, but rather an engineering one, in which techniques are emphasized. The students are expected to participate in a large systems programming design and implementation effort.

#### 411. INFORMATION AND COMPUTER STRUCTURES

Fall term. Credit four hours. Prerequisite: 401 or equivalent. T Th 9:05, W 2:30.

Fundamentals of computer organization and the representation of structured operands in computers. Information flow during instruction execution; addressing structures, symbol table techniques. Algorithms for the manipulation of arrays, trees, strings, lists. Programming language structure; recognition and analysis systems. Time-sharing computer organization, paging, segmenting and core management.

#### 412. COMPUTER LANGUAGE AND COMPILERS

Spring term. Credit four hours. Prerequisite: 411 or consent of the instructor. M W F 1:25.

Concerned with the theory and techniques of programming languages and systems for large scale digital computer systems. Topics include comparison of structure and form of assemblers, interpreters, compilers and list processors; formal definition of algorithmic languages and techniques used in compilation. Students will design and implement several simple languages during the term.

#### 413. SYSTEMS PROGRAMMING

Fall term. Credit four hours. Prerequisite: 412 or consent of the instructor. M W F 1:25.

Brief review of batch process programming systems, their components, operating characteristics, user services and their limitations. Implementation techniques for parallel processing of I/O and interrupt handling. Overall structure of multiprogramming systems on large-scale multiprocessor hardware configuration. Details on addressing techniques, core management, file system design and management, system accounting, and other user-related services. Command languages and the embedding of subsystems. Operating characteristics (parameters) of large-scale systems.

#### 416. OPERATIONS RESEARCH MODELS FOR COMPUTER AND PROGRAMMING SYSTEMS

Spring term. Credit four hours. Prerequisites: 411 and a course in probability (e.g., Math 371, Engineering 9460), or consent of the instructor. T Th 10:10, occasionally W 2:30.

Modeling and analysis of computer hardware and software systems. Some applications of the theories and techniques of operations research to problems

arising in computer systems design and programming. Operating systems design; resource allocation and scheduling. Queueing models for time-sharing and multiprogramming systems. Reliability of computer systems and computer networks. Statistical techniques for measuring systems performance. Simulation of hardware and software; systems balancing. Applications of stochastic processes and inventory theory, e.g., file organization and management, models of computer center operation. Mathematical programming techniques applied to hardware configuration selection. Students will be expected to program and analyze a model which can be applied to a problem of hardware or software design.

#### [417. ADVANCED INFORMATION PROCESSING]

Fall term. Credit four hours. Prerequisite: 401 or equivalent experience. T Th 9:05, W 2:30. Not offered in 1969-70.

#### 420. COMPUTER APPLICATIONS OF NUMERICAL ANALYSIS

Fall term. Credit four hours. Prerequisites: Math 222 or 294 and Computer Science 311 or equivalent programming experience. M W F 9:05.

Modern computational algorithms for the numerical solution of a variety of applied mathematics problems are presented and students solve current representative problems by programming each of these algorithms to be run on the computer. Topics include numerical algorithms for the solution of linear systems; finding determinants, inverses, eigenvalues and eigenvectors of matrices; solution of a single polynomial or transcendental equation in one unknown; solution of systems of nonlinear equations; acceleration of convergence; Lagrangian interpolation and least squares approximation for functions given by a discrete data set; differentiation and integration; solution of ordinary differential equations: initial value problems for systems of nonlinear first order differential equations, [two-point boundary value problems; partial differential equations:] finite difference grid technique for the solution of the Poisson equation.

#### 421-422. NUMERICAL ANALYSIS

Throughout the year. Credit four hours a term. Prerequisite: Math 412 or 416 or 422 or consent of the instructor. M W F 9:05.

A mathematically rigorous treatment of numerical analysis. Covers the topics of 420 in a more complete fashion with emphasis on careful analytical derivation of algorithms, proofs of convergence, and error analysis. Includes some computer programming projects.

#### 435. INFORMATION ORGANIZATION AND RETRIEVAL

Spring term. Credit four hours. Prerequisite: 401 or equivalent. T Th 9:05, occasionally W 2:30.

Covers all aspects of automatic language processing on digital computers, with emphasis on applications to information retrieval. Analysis of information content by statistical, syntactic, and logical methods. Dictionary techniques. Automatic retrieval systems, question-answering systems. Evaluation of retrieval effectiveness.

#### [441. HEURISTIC PROGRAMMING]

Spring term. Credit four hours. Prerequisites: 401 and 411. Not offered in 1969-70.

#### 485. THEORY OF AUTOMATA I

Fall term. Credit four hours. Prerequisite: 401 or Math 481 or consent of the instructor. M W F 11:15.

Automata theory is the study of abstract computing devices, their classification, structure, and computational power. Topics include finite state automata, regular expressions, decomposition of finite automata and their realization, Turing machines and their computation power.

#### 486. THEORY OF AUTOMATA II

Spring term. Credit four hours. Prerequisite: 485 or consent of the instructor. M W F 11:15.

Topics include context-free and context-sensitive languages and their relation to push-down and linearly bounded automata. Quantitative aspects of Turing machine computations: time- and memory-bounded computations with applications to language processing and classification of other automata and computations.

#### 487. FORMAL LANGUAGES

Fall term. Credit four hours. Prerequisite: 401. M W F 2:30.

A study of formal languages, their processing and processors. Topics include regular, context-free, and context-sensitive languages; their recognition, parsing, algebraic properties, decision problems, recognition devices, and applications to computer and natural languages.

#### 488. THEORY OF EFFECTIVE COMPUTABILITY

Spring term. Credit four hours. Prerequisite: 401, 485, Math 481 or consent of the instructor. T Th 9:05.

Turing machines and Church's Thesis, universal Turing machines, unsolvability of the halting problem. Recursively enumerable sets, productive and creative sets, relative computability, the recursion theorem, Post's problem. Computational complexity hierarchies.

#### 521. NUMERICAL ANALYSIS OF LINEAR AND NONLINEAR SYSTEMS OF EQUATIONS

Spring term. Credit four hours. Prerequisite: 422. M W F 9:05.

Topics include recent methods for the solution of linear systems and eigenvalue, eigenvector determination; global convergence theorems for nonlinear systems, Newton-Kantorovich theory and its variations; function minimization.

#### 523. NUMERICAL SOLUTION OF ORDINARY DIFFERENTIAL EQUATIONS AND INTEGRAL EQUATIONS

Fall term. Credit four hours. Prerequisite: 422. M W F 11:15.

Topics include solution of n-th order nonlinear initial value problems and boundary value problems; single step methods; predictor-corrector techniques; stability, accuracy, and precision of methods: eigenvalue problems; solution of integral equations having constant or variable limits: finite difference and iterative methods; singular and nonlinear integral equations.

#### 525. NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS

Spring term. Credit four hours. Prerequisite: 523. M W F 11:15.

General classification; solution by method of characteristics; finite-difference methods for hyperbolic and elliptic equations, parabolic equations in two dimensions; direct solution of elliptic finite-difference equations; iterative methods for the solution of elliptic equations; block methods for large systems; singularities in elliptic equations; stability in relation to initial value problems and nonlinear discretization algorithms.

527. NUMERICAL METHODS IN APPROXIMATION THEORY

Spring term. Credit four hours. Prerequisite: 422. M W F 9:05.

$L_p$  norms; least-square approximation and orthogonal functions; Tchebycheff, asymptotic, rational and continued fraction approximations; the quotient-difference algorithm; methods of descent and ascent.

587. COMPUTATIONAL COMPLEXITY

Fall term. Credit four hours. Prerequisite: 486 or 488, or consent of the instructor. T Th 9:05.

General measures of computational complexity and methods of classifying computable (recursive) functions. Examples of topics include restricted Turing machines, time and memory bounded computations as well as quantitative results about formal languages.

590. SPECIAL INVESTIGATIONS IN COMPUTER SCIENCE

Throughout the year. Credit and sessions to be arranged.

Offered to qualified students individually or in small groups. Directed study of special problems in the Field of Computer Science. (Register only with the registration officer of the department.)

591. COMPUTER SCIENCE GRADUATE SEMINAR

Throughout the year. Credit one hour. For graduate students interested in computer science. Th 4:30-6:00. Staff, visitors, and students.

A weekly meeting for the discussion and study of important topics in the field.

611. SEMINAR IN PROGRAMMING

Spring term. Credit four hours. Prerequisite: 411 or consent of the instructor.

621. SEMINAR IN NUMERICAL ANALYSIS

Fall term. Credit four hours. Prerequisite: consent of the instructor.

635. SEMINAR IN INFORMATION ORGANIZATION AND RETRIEVAL

Fall term. Credit four hours. Prerequisite: 435.

681. SEMINAR IN AUTOMATA THEORY

Spring term. Credit four hours. Prerequisite: 486 or consent of instructor.

ADVANCED DATA PROCESSING SYSTEMS (Engineering 9582)

Fall term. Credit three hours. Prerequisite: 401 or consent of the instructor.

Concerned with design of integrated data processing systems for operational and financial control.

DIGITAL SYSTEMS SIMULATION (Engineering 9580)

Fall term. Credit four hours. Prerequisite: 401 and a course in probability.

The use of a program for a digital computer to simulate the operating characteristics of a complex system in time.

SWITCHING SYSTEMS I (Engineering 4487)

Fall term. Credit three hours. Prerequisite: Engineering 4322 or consent of the instructor.

Topics include switching devices, realization of combinational switching circuits, sequential circuits, arithmetic units in a digital computer.

**SWITCHING SYSTEMS II (Engineering 4488)**

Spring term. Credit three hours. Prerequisite: Engineering 4487 or equivalent.

A continuation of Switching Systems I.

**ELECTRICAL ENGINEERING**

Faculty: Paul D. Ankrum, Joseph M. Ballantyne, Toby Berger, Henry D. Block, Ralph Bolgiano, Neil M. Brice, Nelson H. Bryant, Herbert J. Carlin, Renwick E. Curry, G. Conrad Dalman, Lester F. Eastman, William H. Erickson, Donald T. Farley, Terrence L. Fine, Thomas Gold, Juris Hartmanis, Bernd Hoefflinger, Clyde E. Ingalls, Frederick Jelinek, Myunghwan Kim, Charles A. Lee, Richard L. Liboff, Simpson Linke, Lee A. MacKenzie, Henry S. McGaughan, Paul R. McIsaac, Charles W. Merriam III, John A. Nation, Benjamin Nichols, Robert E. Osborn, Edward Ott, Christopher Pottle, Edwin L. Resler, Jr., Joseph L. Rosson, Neil J. A. Sloane, Howard G. Smith, Ravindra N. Sudan, George Szentirmai, Chung-Liang Tang, James S. Thorp, Hwa Chung Torng, Norman M. Vrana, Leonard S. Wagner, Charles B. Wharton, George J. Wolga, Stanley W. Zimmerman.

Visiting Professors: Rolf B. Dyce, Benjamin Leon

Field Representative: Benjamin Nichols, 230 Phillips Hall.

**MAJOR AND MINOR SUBJECTS**

Electrical Engineering

Electrophysics

Electrical Systems

Considerable latitude is allowed in the selection of the minor subjects provided that the entire program shows a unified purpose.

Adequate work in advanced physics and mathematics is required of candidates for the degree of Ph.D. At least one of the two minor subjects must be chosen outside the Field of Electrical Engineering.

The appropriate major and minor subjects listed above define broad areas in the Field of Electrical Engineering within which a student may plan a graduate program which best suits his needs. In addition to the formal courses listed below, members of the faculty are prepared to guide individual students in special topics and to arrange seminars for students interested in closely related lines of study and research. Proficiency is expected in all phases of the graduate program.

**ADMISSION REQUIREMENTS.** Though the Graduate Record Examination is not required in the Field of Electrical Engineering, applicants are urged to take this examination, submitting its results along with their application for graduate work.

As a prerequisite for graduate work leading to the degree of M.S. or Ph.D. with a major in the Field of Electrical Engineering, the candidate should have had the equivalent of the fundamental work required by an accredited undergraduate curriculum in the area of his major subject. The candidate must also supply definite evidence of scholarly interest and aptitude for advanced study.

**LANGUAGE REQUIREMENTS.** There is no foreign language requirement for the M.S. degree.

For admission to Ph.D. candidacy, a student is required to demonstrate proficiency in one modern foreign language.

**EXAMINATIONS.** The Field of Electrical Engineering requires that every Ph.D. student complete successfully a qualifying examination prior to taking the Admission to Candidacy Examination.

For the Master of Science Degree a final examination is required.

Examinations as required by the Graduate School (see page 12) are conducted by the student's Special Committee.

## Faculty Research Interests

Members of the faculty in the Field of Electrical Engineering are especially interested in directing graduate research in the following areas:

**ELECTRICAL ENGINEERING.** Applied mathematics; biomedical electronics; electrical measurements; instrumentation, computer-aided design; conversion, transmission and control of electric energy; magnetohydrodynamics.

**ELECTRICAL SYSTEMS.** Analysis and synthesis of time-variable and non-linear systems; switching systems and digital processing; control systems; optimization and adaptation; information theory; random processes; signal processing; pattern recognition; network theory.

**ELECTROPHYSICS.** Microwave electronics; masers, lasers, quantum electronics; plasma physics; ionospheric studies; radio astronomy; solid-state physics and devices.

It is not desirable, nor is it intended, that the boundaries between these areas be too rigidly defined. Rather, every effort is made to allow each student to pursue a program designed to give him a period of broad advanced study. To this end, work in such subjects as applied physics, astronomy, computer science, biological science, engineering materials, fluid mechanics, or thermodynamics may be considered as partially fulfilling the requirements for a major or minor in Electrical Engineering, even though these subjects are not under the direct jurisdiction of the faculty of the School of Electrical Engineering.

## Financial Aid

In addition to several University-wide fellowships, the following are available for electrical engineering degree candidates:

*John McMullen Graduate Fellowship.* \$2,000 plus tuition and fees.

*AEC Traineeships in Nuclear Science and Engineering.* Stipends similar to NSF and NASA Traineeships.

*IBM Fellowship.* \$1,800 plus tuition and fees. Provision for an additional \$700 if candidate is married and has at least one child. Open to candidates in the Fields of Applied Physics, Electrical Engineering, and Operations Research.

*NASA Traineeships.* Available on a twelve-month basis in amounts of \$2,400 to \$2,800 plus tuition and fees. A \$600 allowance is available if recipient is married and has one or more children. Open to United States citizens.

*General Telephone and Electronics Laboratory Fellowship.* \$2,100 plus tuition and fees.

*National Science Foundation Traineeships.* Available on a nine- or twelve-month basis. Stipends are \$2,400, \$2,600, and \$2,800 on a twelve-month basis



for first, second, and third years respectively. Tuition and fees will be paid, and \$500 per dependent is allowed on the twelve-month basis. Candidates must be United States citizens.

*Xerox Fellowship.* \$3,500 plus tuition and fees. Open to students in the first year of graduate study majoring in any of the fields encompassed by the Materials Science Center, such as Electrical Engineering, Applied Physics, Materials Science and Engineering, and Theoretical and Applied Mechanics.

*Michael Faraday and James Clerk Maxwell Fellowships* of the Aeronautical Laboratory. Range from \$2,000 up plus tuition and fees. Provision for an additional \$600 if recipient is married.

*United States Steel Foundation Fellowship.* \$1,500 plus tuition and fees. Provision for an additional \$600 if recipient is married.

*Charles Bull Earle Memorial Graduate Fellowship.* \$600 plus tuition and fees. The stipend may be supplemented in special cases.

There are also several teaching fellowships and research assistantships available paying \$2,000 and tuition and fees with adjustments upward to \$2,800 for additional qualifications and experience. Research assistantships may be granted for full-time summer work paying \$1,000.

A prospective graduate degree candidate is invited to direct his inquiries to the Graduate Field Representative for Electrical Engineering, 230 Phillips Hall.

## Professional Degree

The Master of Engineering degree is the only professional engineering degree offered by Cornell University. Admission to the Master of Engineering (Electrical) degree program is open to persons who have been granted Bachelor's degrees, or the equivalent, and who have sufficient training to indicate that they can profitably study the advanced courses offered for these students in the School of Electrical Engineering. The purpose of this degree program is to offer depth of study in both comprehensive and specialized electrical engineering subjects, and to offer study extending the abilities of the electrical engineer to other areas.

In addition to the general requirements for the degree (see page 12), a further requirement for the Master of Engineering (Electrical) is a minimum of two sequences of two courses each in advanced electrical engineering (chosen from a designated list).

Graduates of Cornell University with a Bachelor of Electrical Engineering degree may be granted up to fifteen hours of credit for advanced courses taken during the fifth undergraduate year, provided they enter the M.Eng.(E) program not later than the fall term following the sixth anniversary of their receiving the B.E.E. degree. For those students who are granted fifteen credit hours of advanced standing, the requirement is six credit hours in the School of Electrical Engineering rather than two sequences of two courses each, and the design requirement may be waived.

## Elective and Graduate Courses

Of the following elective and graduate courses, certain ones may not be offered every year if the demand is considered to be insufficient.

## THEORY OF SYSTEMS AND NETWORKS

## 4501. SYSTEMS WITH RANDOM SIGNALS

Fall term. Credit four hours. Three lectures, one recitation. Prerequisite: 4402 or equivalent.

Linear systems and signals; probability and random variables; random processes in communication systems; spectral analysis of random processes; filtering of random signals; band-pass signals and noise; envelope detection of signals and noise; post detection filtering; nonlinear receiver operations; modulation systems; time and frequency multiplex systems; noise in analog modulation systems.

## 4502. STATISTICAL ASPECTS OF SYSTEM ANALYSIS

Spring term. Credit four hours. Three lectures, one recitation. Prerequisite: 4501.

Digital transmission systems; the discrete transmission channel; elements of information transmission and coding; information capacity; system optimization; linear least squares prediction and smoothing; matched filters; optimum receivers; hypothesis testing; parameter estimation; the matched filter and the correlation receiver; wave-form systems and signal design; error probabilities and error bounds for various systems.

## 4503. THEORY OF LINEAR SYSTEMS

Fall term. Credit four hours. Three lectures. Prerequisite: 4401 or consent of the instructor.

The state-space model for linear systems. Properties of ordinary linear differential equations. Fundamental and transition matrices. Matrix exponential functions, the Cayley-Hamilton theorem and the Jordan form. Time invariant and time-varying network and system response. Controllability, observability, stability. Realizability of linear casual systems and applications of Fourier, Laplace, Hilbert transforms. Paley-Wiener theorem. Distributed systems. At the level of Schwarz and Friedland, *Linear Systems*.

## 4504. THEORY OF NONLINEAR SYSTEMS I

Spring term. Credit four hours. Three lectures. Prerequisite: 4503 or 4501 or 4571 or consent of the instructor.

Lagrangian formulation. Analysis of first- and second-order nonlinear systems with applications. Phase plane analysis of autonomous systems; singular points, limit cycles, and equilibrium states; theories of Bendixson, Lienard, and Poincare; relaxation behavior in the phase plane; perturbation theory, existence, convergence and periodicity of perturbation series; the methods of van der Pol, and Krylov and Bogoliubov. Forced nonlinear systems, harmonics, subharmonics, jump phenomena, and frequency entrainment; periodic systems, Floquet theory, Mathieu-Hill theory, applications to the stability of nonlinear systems and to parametrically-excited systems.

## 4505-4506. OPTIMIZATION AND APPROXIMATION TECHNIQUES I AND II

Fall and spring terms. Credit four hours. Three lectures. Prerequisites: 4402 and current registration in 4503 or consent of the instructor.

Optimization and approximation techniques used in the synthesis of systems and signals, with applications in control and communication. Signal approximation problems; Kautz filters, measurement of expansion coefficients, complementary filters. Examples of signal approximation problems in biological and electrical systems. Optimum pole positions for exponential ap-

proximation. Computational methods for parameter optimization and approximation problems. Formulation of deterministic control optimization problems; minimal time, minimal fuel, regulator problems. Introduction to variational methods. Solution of two-point boundary-value problems by control vector iteration. Statistical optimization problems. Synthesis of optimal filters and feedback controllers.

#### 4507-4508. RANDOM PROCESSES IN ELECTRICAL SYSTEMS

Fall and spring terms. Credit four hours. Three lectures.

The concepts of randomness and uncertainty and their relevance to the design and analysis of electrical systems. An axiomatic characterization of random events. Numerically valued events: random variables and random vectors. Distribution functions and densities. Functions of random vectors. Expectation and measures of fluctuation. Moment and probability inequalities. Properties and applications of characteristic functions. Convergence of sequences of random variables: laws of large numbers and central limit theorems. More general collections of random variables, random processes. Random processes as signal or system models and their specification. Sample function behavior. Markov processes, particularly chains and the Poisson process. Stationarity and ergodicity. The Gaussian process. Wide sense stationary processes: correlation functions, spectra. Representations of random processes. Transformations of random processes by nonlinear devices and filters. Optimum filtering theories.

#### 4571. NETWORK ANALYSIS

Fall term. Credit four hours. Three lectures. Open to qualified seniors.

Introduction to network topology. Scattering, immittance, hybrid, and state-space formalisms for networks. Steady state analysis and power transfer in n-port networks including nonreciprocal and active structures. Scattering properties and realizability theorems for lossless multiport junctions. Analysis of transmission line networks. At the level of Carlin and Giordano, *Network Theory: An Introduction to Reciprocal and Non-Reciprocal Circuits*.

#### 4572. NETWORK SYNTHESIS

Spring term. Credit four hours. Three lectures. Prerequisite: 4571 or 4503 or consent of instructor.

Physical basis for network techniques in lumped and distributed systems deduced from linearity, time-invariance, and power-energy constraints. Generalized bounded real and positive real functions and matrices and the theory of physical realizability. Applications to insertion loss synthesis, synthesis of n-ports, design of transmission line filters and equalizers. RC-lines. Gain bandwidth theory of active devices. Synthesis of active networks.

#### 4601. THEORY OF NONLINEAR SYSTEMS II

Spring term. Credit four hours. Three lectures. Prerequisite: 4504 or consent of the instructor.

Nonautonomous and higher order nonlinear systems with applications; representation of systems with several degrees of freedom; approximations; use of Lyapunov functions in system stability determination and design; describing functions and Aizerman's hypothesis, theory of Lur'e-Letov for nonlinear control; asymptotic expansions for the period behavior of systems under the influence of periodic external forces; method of averaging; systems with slowly varying parameters, Manley-Rowe relations; orthogonal representation of nonlinear systems; nonlinear filters and compensating systems, system optimization.

## 4603. THEORY OF LINEAR SYSTEMS II

Fall term. Credit four hours. Three lectures. Prerequisite: 4503.

Rigorous developments of linear graph theory and of linear transformations with applications to control and communication systems. Topological properties of weighted graphs, signal-flow graphs, communication nets. Algebraic methods. Signal analysis. Functionals and properties, model making. Linear function spaces with applications to system realization, stability and sensitivity. Asymptotic expansions.

## 4604. UNIFIED THEORY OF ELECTROMECHANICAL SYSTEMS

Credit three hours. Two lectures, one computation period. Prerequisite: 4441, 4442, or consent of the instructor.

Electric machines studied as networks of coupled circuits with periodically varying parameters; forces and torques in electromechanical systems; electromagnetic and electrostatic transducers; Kron's basic machine with its practical derivatives; the synchronous, induction and commutator machines in the transient and steady state; frequency response methods applied to machines.

## ELECTROMAGNETIC THEORY

## 4511. ELECTRODYNAMICS

Fall term. Credit four hours. Three lectures, one recitation. Prerequisites: 4312 or equivalent and coregistration in Mathematics 421 or equivalent.

Foundations of electromagnetic theory. Statics: multipole distributions, images and potential theory. Elements of magnetostatics. Maxwell's equations. Wave guides and cavities. Stress-energy tensor. Gauge invariance. Poynting's theorem. Radiation theory. Postulates of relativity. Lienard-Wiechert potentials. Synchrotron and Cherenkov radiation. Energy and angular momentum of the radiation field. Radiative reaction force. Electromagnetic force.

## 4514. MICROWAVE THEORY

Spring term. Credit four hours. Three lectures, one recitation. Prerequisite: 4511 or equivalent.

Theory of passive microwave devices for propagating, storing, coupling, or radiating microwave energy, including the theory of uniform and periodic waveguides, cavities, junctions, and antennas; application of inhomogeneous, anisotropic, dispersive, or nonlinear dielectric and magnetic materials to microwave devices; circulators, isolators, tunable filters, limiters, artificial dielectrics; techniques of analysis, including use of orthogonal functions, perturbation theory, variational techniques, Green's functions, and symmetry principles.

## 4567. ANTENNAS AND RADIATION

Spring term. Credit three hours (four hours with laboratory). Three lectures; laboratory (optional). Prerequisite: 4312, 4401 or equivalent.

Formulation of the electromagnetic field in terms of vector and scalar potentials; radiation from elemental electric and magnetic dipoles. Linear radiators: radiation from short dipoles, small loops; resonant wire antennas; long wire antennas, linear arrays and pattern synthesis; impedance properties of wire antennas, including mutual impedance, parasitic elements; wire receiving antennas. Aperture antennas: uniqueness theorem for vector fields, equivalence and induction principles; radiation from open-ended waveguides, horn antennas, reflector antennas; Babinet's principle; slot antennas. At the level of Jordan, *Electromagnetic Waves and Radiating Systems*.

## 4568. ADVANCED ANTENNA METHODS AND PROBLEMS

Spring term. Credit three hours. Three lectures. Prerequisites: 4567 or equivalent, and 4511 or equivalent.

Huygens' principle for electromagnetic fields, application to problems of diffraction and aperture radiators; surfacewave antennas; various specialized antennas, helical, log periodic, radio astronomy systems, space and satellite systems; radiation in dielectric and plasma media, including media in motion; antenna thermodynamics.

## ELECTRONICS

## 4431-4432. ELECTRONIC CIRCUIT DESIGN

Throughout the year. Credit three hours per term. Two lecture-recitations, one laboratory. Prerequisite: 4322.

Design techniques for circuits used in electronic instrumentation. Circuits will be designed to provide specific functions, then constructed and tested in the laboratory. At the level of Millman and Taub, *Pulse Digital and Switching Waveforms*.

## 4433. SEMICONDUCTOR ELECTRONICS I

Fall term. Credit four hours. Three lectures, one laboratory. Prerequisites: 4302 and 4322.

Band theory of solids; properties of semiconductor materials; the physical theory of p-n junctions, metal-semiconductor contacts, and p-n junction devices; device fabrication; properties of semiconductor devices such as diodes and rectifiers, light-sensitive and light-emitting devices, field-effect and bipolar transistors, unijunction transistors, p-n-p-n devices (diodes, controlled rectifiers and switches), etc.; device equivalent-circuit models; field-effect and bipolar transistor amplifier stages. At the level of the *Semiconductor Electronics Education Committee (S.E.E.C.) Series*, Vols. 1-4.

## 4434. SEMICONDUCTOR ELECTRONICS II

Spring term. Credit four hours. Three lectures, one laboratory. Prerequisite: 4433.

A continuation of Semiconductor Electronics I with emphasis on the application of semiconductor devices as active or passive elements in circuits for use as power supplies, power controls, amplifiers, oscillators and multi-vibrators, pulse circuits, gates and switches, etc.; transistor noise; integrated circuits. At the level of the *S.E.E.C. Series*, Vols. 5 and 6 and *Semiconductor Controlled Rectifiers: Principles and Application of p-n-p-n Devices*, by Gentry, et al.

## 4531. QUANTUM ELECTRONICS I

Fall term. Credit four hours. Three lectures, one recitation-computation. Prerequisites: 4311, 4312, and Physics 443 or 4411.

A detailed treatment of the physical principles underlying microwave and optical masers and related fields. Topics will include a brief review of quantum mechanics and the theory of angular momentum; spectroscopy of free atoms and ions with particular emphasis on the application of the results to neutral and ionized noble gas masers; theory of interaction of radiation and matter; quantum theory of coherence; a thorough study of the steady-state and dynamic characteristics of microwave and optical masers. At the level of Yariv, *Quantum Electronics*.

**4532. QUANTUM ELECTRONICS II**

Spring term. Credit four hours. Three lectures, one recitation-computation. Prerequisite: Quantum Electronics I or consent of the instructor.

A continuation of the treatment of the physical principles underlying masers and related fields. Topics will include a consideration of microwave and optical spectroscopy of impurity ions in solids with particular emphasis on the application of the results to microwave and optical solid state masers; density matrix and its applications in the study of masers and related problems; nonlinear optical phenomena and multiplephoton processes; interaction of intense light waves with molecular vibrations and elastic waves; theory and properties of molecular and semiconductor masers; characteristics of optical resonators. At the level of Yariv, *Quantum Electronics*.

**4535. SEMICONDUCTOR DEVICES I**

Fall term. Credit four hours. Three lectures. Prerequisite: 4412 or equivalent.

A study of the properties of semiconductor devices with emphasis on low frequency operation (below 1,000 GHz). Devices based on the tunnel effect: tunnel diodes, field emitter cathodes, thin film resistors. Devices based on charge flow across semiconductor-semiconductor contacts: p-n diodes, avalanche diodes, transistors, field-effect transistors, unipolar transistors. Devices based on metal-semiconductor contacts: Schottky diode, Schottky triode. Emphasis is placed on determining the factors determining performance capabilities. Equivalent circuits are developed. The student will carry out either a term laboratory project or prepare a term paper on an appropriate contemporary topic. The course is presented at the level of Moll, *Physics of Semiconductors* and of current papers published in the *IEEE Transactions on Electron Devices*.

**4536. SEMICONDUCTOR DEVICES II**

Spring term. Credit four hours. Three lectures. Prerequisite: 4551 or equivalent.

A study of the properties of semiconductor devices with emphasis on high frequency operation (above 1,000 GHz). The approaches to the analysis to be studied are: Ballistic analysis, electronic-network analysis (Llewellyn-Peterson), space-charge wave and coupled-mode analysis. Devices studied include: avalanche microwave diode. (Read diode), microwave transistors, tunnel diodes, Gunn oscillators, injection lasers. Emphasis is placed on determining the factors that determine the performance capabilities. Equivalent circuits are developed. The student will carry out either a term laboratory project or prepare a term paper on an appropriate contemporary topic. The course is presented at the level of current papers published in the *IEEE Transactions on Electron Devices*.

**4538. ELECTROMAGNETIC PROPERTIES OF SOLIDS**

Spring term. Credit four hours. Three lectures, one recitation. Prerequisites: Physics 454, or 4412 and 4511 (Electrodynamics), or consent of the instructor.

Microscopic interpretation of complex permittivity and permeability; electronic, atomic, orientation and space charge polarization; interaction of elementary magnetic moments; dielectric dispersion via resonance and relaxation, plasma resonance; quantum theory of dielectric constant; local internal field and spontaneous ordering; introductory lattice dynamics, lattice frequency spectrum, introductory group theory and application to derivation of selection rules for infrared and Raman active normal modes; extended frequency analysis of vibrational spectra.

**4631-4632. THE PHYSICS OF SOLID STATE DEVICES**

Fall and spring terms. Credit two-three hours per term by permission of instructor. Two lectures. Prerequisite: 4536 or permission of instructor.

The analysis of solid state devices of current interest (Avalanche, LSA, Gunn devices, etc.) will be considered in sufficient detail to understand some of the limitations of analysis and/or physical understanding that are involved in the design of such devices. Toward this end the relevant aspects of the transport properties of warm and hot charge carriers and the complications of band structure will be considered. In order to deal thoroughly with these basic aspects the number of devices considered will be limited, but subjects of specific interest to individuals may be considered on a seminar basis.

**POWER SYSTEMS AND MACHINERY****4441. CONTEMPORARY ELECTRICAL MACHINERY I**

Fall term. Credit three hours. Two lecture-recitation periods, one laboratory-computation period. Prerequisite: 4302.

Emphasis on engineering principles. Real and reactive power requirements of core materials with symmetrical and with biased magnetizing forces; analysis and characteristic prediction of high-efficiency transformers; magnetic amplifiers, energy transfers among electric circuits, magnetic fields and mechanical systems; control of magnetic field distribution by reluctance and winding distribution; travelling fields from polyphase excitation; elementary idealized commutator-type, asynchronous, and synchronous machines.

**4442. CONTEMPORARY ELECTRICAL MACHINERY II**

Spring term. Credit three hours. Two lecture-recitation, one laboratory-computation period. Prerequisite: 4302.

Emphasis on engineering principles. Production of air-gap magnetic fields; elementary and idealized rotating machines; steady-state and transient characteristics of realistic rotating machines; a-c commutator-type single-phase motors; polyphase synchronous, and single-phase induction machines; recently developed types: Saturistor motor, self-excited a-c generators; miscellaneous rotary devices; Hysteresis motor, selsyns, amplidynes, frequency converters.

**4443. POWER SYSTEM EQUIPMENT**

Fall term. Credit three hours. Two lectures, one computation period. Prerequisite: 4302.

System equipment and control parameters are studied. Test requirements for electrical apparatus for conventional and nuclear electrical power production and distribution are considered. Prime movers, generators and their accessories, switchgear, protective devices, power transformers, converters, towers, conductors, regulating devices, and data gathering and computer control systems are analyzed. Inspections of nearby station equipment are planned to supplement classroom work.

**4444. HIGH VOLTAGE PHENOMENA**

Spring term. Credit three hours. Prerequisite: 4302.

The study of problems of the normal operation of power systems at very high voltages, of the abnormal conditions imposed by lightning, of the methods employed to assure proper operation of power systems and apparatus under high-voltage conditions, and of the devices available for laboratory testing of equipment under actual or simulated conditions. An invitation to visit electrical manufacturing test facilities is usually accepted. Considerable attention is given to dielectric behavior and testing techniques.

## 4445-4446. ELECTRIC ENERGY SYSTEMS I AND II

Fall and spring terms. Credit four hours per term. Three lecture-recitation-computations. Prerequisites: 4422 or 4302 and consent of the instructor.

The physical and engineering principles underlying steady-state and transient operation and control of modern electric-power systems, with emphasis on the characteristics of major power-system parameters. Theory of electromechanical energy converters, power transformers, conventional transmission lines and cables, high-voltage-direct-current systems, power networks and other power-system components; use of the digital computer as a dynamic "laboratory" model of a complex power system for load flow, fault, transient stability and economic-analysis studies. Laboratory-computing periods will include selected experiments with electromechanical energy converters. At the level of Stevenson, *Elements of Power System Analysis*, 2nd Edition.

## RADIO AND PLASMA PHYSICS

## 4461. WAVE PHENOMENA IN THE ATMOSPHERE

Fall term. Credit three hours. Three lecture-recitation periods. Prerequisites: 4302 and 4312.

An elementary treatment of wave phenomena in the atmosphere of the earth including gravity waves, planetary waves, acoustic waves, radio waves, and plasma waves; attention is directed to the role of these phenomena in various atmospheric processes and engineering problems, such as weather, pollution, radio communication, atomic fallout.

## 4462. RADIO ENGINEERING

Spring term. Credit three hours. Three lecture-recitation periods. Prerequisite: 4312 and 4402.

A study of electrical systems for communication, control, detection, and other purposes, in which radiowaves (wireless) play a central role; system functions, including generation, modulation, transmission, reception, and demodulation; guidance, radiation, and propagation of radiowaves, including transmission lines and waveguides, antenna systems, and the effects of atmospheric inhomogeneity; system design problems.

## 4464. ELEMENTARY PLASMA PHYSICS AND GAS DISCHARGES

Spring term. Credit three hours. Two lectures, one laboratory. Prerequisite: 4312 or equivalent.

A review of electromagnetic wave theory. Plasma as a dielectric medium, plasma oscillations and waves, interaction of E. M. waves with a plasma, gas discharges, positive column, plasma sheath, Langmuir probes, collisions, magnetohydrodynamics, MHD generator.

Laboratory work will include experiments with microwave circuits, gas discharges, lasers and application of measurement techniques to laboratory plasmas.

## 4451-4552. UPPER ATMOSPHERE PHYSICS I AND II

Fall and spring terms. Credit three hours each term. Three lectures.

The physical processes governing the behavior of the earth's ionosphere and magnetosphere will be considered. Topics covered will include the production, loss, and transport of charged particles in the ionosphere and magnetosphere; temperature variations; airglow; tidal motions, winds, and gravity waves in the ionosphere; the electrical conductivity of the ionosphere, the dynamo current system, and the equatorial and auroral electrojets; the inter-



action between the magnetosphere and the solar wind; the acceleration and drift of energetic particles in the magnetosphere; the precipitation of particles and the aurora; magnetic and ionospheric storms.

#### 4561. INTRODUCTION TO PLASMA PHYSICS

Fall term. Credit three hours. Three lectures. Prerequisites: 4311 and 4312 or equivalent.

Plasma state; motion of charged particles in fields; adiabatic invariants, collisions, coulomb scattering; Langevin equation; transport coefficients, ambipolar diffusion, plasma oscillations and waves; hydromagnetic equations; plasma confinement, energy principles and macroscopic instabilities; test particle in a plasma; elementary applications. At the level of Longmire, *Elementary Plasma Physics*.

#### 4562. WAVES IN PLASMAS

Spring term. Credit three hours. Three lectures. Prerequisite: 4561.

Magnetoactive cold plasma theory, CMA diagrams, plasma and cyclotron waves, whistlers, hydromagnetic waves, bounded plasmas, shocks, radiation; applications to laboratory and natural phenomena. At the level of the first half of Stix, *Theory of Plasma Waves*.

#### 4564. ADVANCED PLASMA PHYSICS

Spring term. Credit three hours. Three lectures. Prerequisite: 4561.

Boltzmann and Vlasov equations; moments of kinetic equation, Chew-Goldberger-Low theory, waves in hot plasmas, Landau damping, instabilities due to anisotropies in velocity space, gradients in magnetic field, temperature and density, etc.; effects of collisions and Fokker-Planck terms; high frequency conductivity and fluctuations, quasi-linear theory; nonlinear wave interaction, weak turbulence and turbulent diffusion.

#### 4565-4566. RADIOWAVE PROPAGATION I AND II

Fall and spring terms. Credit three hours each term. Three lectures. Prerequisites: 4312 and 4401 or equivalent.

Propagation in the earth's environment: the troposphere, ionosphere, magnetosphere, and interplanetary space. Topics covered will include diffraction and surface wave propagation; tropospheric refraction and ducting; propagation in the ionospheric plasma including magnetoionic theory, the CMA diagram, cross-modulation and Faraday rotation, whistler-mode propagation, ion effects and ion whistlers, group velocity and ray tracing, WKB solutions of the coupled-wave equations, and full-wave solutions; interactions between particles and waves in the magnetosphere; radar astronomy; the scattering of radio waves from random fluctuations in refractive index-tropospheric and D region-ionospheric scatter propagation, incoherent scatter from the ionosphere and its use as a diagnostic tool, radio star and satellite scintillations and their use in studying the ionosphere and solar wind.

### COMMUNICATIONS

#### 4472. INTRODUCTION TO ALGEBRAIC CODING

Spring term. Credit three hours. Three lectures. Prerequisite: Math 293 or equivalent.

Intended for students interested in information theory or digital systems. Codes for correcting errors in data transmission or processing: Group codes, Hamming codes, Bose-Chaudhuri codes. Bounds on performance. Codes for

data compression and storage; variable-length codes, prefix codes. Codes for synchronization and their application to location of distant objects by radar. Analysis of these codes in terms of the underlying algebraic theory. Implementation by sequential machines. The algebraic theory (groups, fields, etc.) will be developed as needed.

#### 4673. PRINCIPLES OF ANALOG AND DIGITAL COMMUNICATION

Fall term. Credit four hours. Three lectures. Prerequisite: 4508 or consent of the instructor.

Uses the fundamentals of information theory, signal theory, and statistical estimation and decision theory to formulate approaches to the solution of problems arising in digital and analog communication. Particular topics include: receiver and signal design, probability of error, capacity, threshold effects for the additive Gaussian channel. Extensions to the additive Gaussian channel: feedback, random gain and phase, diversity. Time-variant Gaussian channels; receiver and signal design, probability of error, and capacity. At the level of Viterbi, *Principles of Coherent Communication*.

#### 4674. TRANSMISSION OF INFORMATION

Fall term. Credit four hours. Three lectures. Prerequisite: 4507 or Mathematics 571 or consent of the instructor.

Applies information theory to the analysis and design of communication systems. Selection of fidelity criteria for accurate and efficient transmission of information. Efficient representation of outputs of message sources. The entropy measure and its properties. Encoding for reliable communication through discrete memoryless noisy channels. Rate of information transmission and the probability of decoding error, channel capacity. Systematic codes and the instrumentation problems. Sequential decoding. Coding and decoding for the band-limited Gaussian channel. Coding of sources with a fidelity criterion. At the level of F. Jelinek, *Probabilistic Information Theory*.

#### 4676. DECISION AND ESTIMATION THEORY FOR SIGNAL PROCESSING

Fall term. Credit four hours. Three lectures. Prerequisite: concurrent registration in 4507 or Mathematics 571.

An examination of selected decision and estimation problems encountered in the design and analysis of radar/sonar target discrimination, signal demodulation, and pattern classification systems. The hypotheses of risk and uncertainty, the role of objectives, criteria for evaluating decision or estimation procedures and characteristics of such procedures. Additional topics, drawn from the fields of parametric and nonparametric statistics, empirical time series analysis, and nonprobabilistic decision or estimation procedures, will be treated as required for the resolution of the selected problems.

### COMPUTING SYSTEMS AND CONTROL

#### 4481-4482. FEEDBACK CONTROL SYSTEMS

Fall and spring terms. Credit four hours. Prerequisite: 4302 or consent of the instructor.

Principles of feedback control systems with emphasis on methods of analysis and synthesis to meet prescribed performance criteria. One-sided Laplace transform applications; electronic, electromechanical, electrohydraulic, and pneumatic components; cascade and feedback compensation of linear control systems. Common physical nonlinearities encountered in control systems; phase

plane and describing function; nonlinear compensation; dual mode systems; relay control systems; Z-transform; analysis of sampled data systems; digital compensation; optimization of sampled data systems. Laboratory work consists of experiments in: components, transient and frequency response measurements; compensation on linear and nonlinear control systems; simulation, design and optimization of control systems by analog and digital computers; projects of the student's choice. At the level of *Control System Analysis and Synthesis*, by D'azzo and Houpsis.

#### 4483. ANALOG COMPUTATION

Fall term. Credit four hours. Two lectures, one laboratory. Prerequisite: concurrent registration in 4401 or an equivalent background with consent of the instructor.

Concepts and principles of analog computation and simulation as applied to engineering analysis and design. Linear, time varying, and nonlinear differential equations. Automatic iterative and basic optimization techniques using digital logic. Laboratory work with general-purpose analog computers. Course develops fundamental ideas to include subjects at the level of Levine, *Methods of Solving Engineering Problems Using Analog Computers*.

#### 4484. ANALOG-HYBRID COMPUTATION

Spring term. Credit three or four hours. Two lectures, one laboratory. Prerequisite: 4483.

Theory, design, characteristics, and programming of analog-oriented hybrid computer systems; analog-digital computer linkage components; error analysis and error compensation in hybrid computation; theory and laboratory work on analog iterative procedures, boundary-value problems, optimization and random search. The laboratory work will make use of an analog computer linked with digital logic components.

#### 4487-4488. SWITCHING THEORY AND SYSTEM

Fall and spring terms. Credit three or four hours per term. Three lectures, one optional laboratory. Prerequisite: Mathematics 293-294 or equivalent; first term prerequisite to second.

Mathematical foundation, switching devices, logical formulation and realization of combinational switching circuits; function minimization and decomposition, fault detection and diagnosis; implementation algorithms; threshold logic; number representation and codes; iterative network; simple memory devices; synchronous and asynchronous sequential circuit, regular expression; circuit equivalence; decomposition theorems and algorithms for secondary assignments; hazards in switching circuits; logic design of general-purpose digital computers.

Topics for the optional laboratory session: design and construction with solid-state modules of counters, shift registers, adders, other arithmetic circuits in a digital computer, and general sequential networks.

#### 4588. BIONICS AND ROBOTS (Engineering 1157)

Spring term. Credit three hours. Three lectures. Prerequisites: Elementary Differential Equations, Linear Algebra and Probability, or consent of instructor.

Engineering applications of strategies and tactics of biological systems. Machines that learn. Artificial intelligence. Cybernetics. Information and adaptive control. Reliable systems from unreliable components. Self-organizing systems. Features in patterns. Neural nets, perceptrons, threshold logic, madelines. Brain models. Behavior models. Machines for proving theorems,

playing games, navigating, exploring. Problems of sensors, perception, recognition and recall. Problems of a machine to learn concepts, English, natural environments. Machine translation. Heuristic programming. Automata, pure and applied. Robots, hardware and software. Self-reproducing and self-repairing machines; models for embryology, development and evolution. Introduction to algebraic linguistics, Turing machines, and computability, Gödel's theorem, the Euler-Diderot metatheorem.

#### 4681. RANDOM PROCESSES IN CONTROL SYSTEMS

Fall term. Credit four hours. Three lectures. Prerequisites: 4574 and 4584.

Prediction and filtering in linear control systems; Gaussian-Markov sequence, Gaussian-Markov process, prediction problem, Hamiltonian formulation of filtering problem, generalized Wiener filtering, stochastic optimal and adaptive control problems. Selected topics: Bayes decision rule, min-max policy, maximum likelihood estimate, control of systems with uncertain statistical parameters; stochastic differential equations, optimal nonlinear filtering; Gaussian input describing function, stability of control systems with random parameters.

### GENERAL

#### 4421-4422. ADVANCED ELECTRICAL LABORATORY

May be taken in the fall and spring consecutively or separately. Credit four hours. One lecture, two laboratories. Prerequisite: 4322 or consent of the instructor.

Advanced experiments concerning a wide range of topics appropriate to electrical engineering, and lectures concerning experimental techniques and practical aspects of electronics. About thirty different experiments are available concerning topics of transistor and tube amplifiers, feedback, class-C amplifiers and oscillators, gyrators, doubletuned circuits, push-pull amplifiers, multi-vibrators, operational amplifiers, switching systems, oscillator synchronization, noise properties, microwave circuits, microwave propagation and scattering, semiconductor properties such as the hall effect and minority carrier mobility, helicon waves, Gunn and avalanche diode oscillators, lasers, propagation of electromagnetic waves, antennas, and a-c and d-c machines. The student is expected to perform three or four experiments per term, selected to meet his needs. Emphasis is placed upon independent work.

#### 4520. GRADUATE LABORATORY

Fall normally, but either term if demand is sufficient. Credit three hours. One laboratory.

Choice of three to five experiments in the fields of solid-state and quantum electronics, microwave electronics, vacuum and physical electronics, optics, radio and communication circuits, networks, transmission lines, antennas, propagation of electromagnetic waves, plasma physics, and electrical machinery.

#### 4591 and 4592. PROJECT

Fall and spring terms. Credit three hours.

Individual study, analysis, and usually experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing his project; an engineering report on the project is required.

#### 4593. FUNDAMENTALS OF ACOUSTICS

Fall term. Credit four hours. Three lectures, one laboratory.

Given at the level of *Fundamentals of Acoustics*, by Kinsler and Frey. In-

tended for first year graduate students and qualified seniors. Vibrations in strings, bars, membranes and plates; plane and spherical acoustic waves; transmission, reflection, absorption, resonators, filters; loudspeakers and microphones; speech, hearing, and noise; architectural acoustics; ultrasonic and sonar transducers; underwater acoustics.

#### 4595—4596. ELECTRICAL ENGINEERING DESIGN

Fall and spring terms. Credit three hours per term.

Offered for students enrolled in the M.Eng.(E.) program. Utilizes real engineering situations in which to present fundamentals of engineering design.

#### 4690—4699. SPECIAL TOPICS IN ELECTRICAL ENGINEERING

Either term. Credit one to three hours.

Seminar, reading course, or other special arrangement agreed upon between the students and faculty members concerned.

## GEOLOGICAL SCIENCES

(Geology, Geochemistry, Geophysics, Geobiology, Physical Geography, Applied Fields)

Faculty: Arthur L. Bloom, L. L. Y. Chang, Kenneth F. Clark, George A. Kiersch, Shailer S. Philbrick, John W. Wells. (Two professors to be appointed.)

Visiting Professor: Edwin D. McKee, United States Geological Survey, Denver, Colorado. (Fall term, 1969.)

Field Representative: George A. Kiersch, 140 McGraw Hall.

### MAJOR SUBJECTS

Areal Geology	Geobiology, Paleontology, and
Engineering Geology	Stratigraphy
Geohydrology and Hydrogeology	Mineral Deposits, Mining
Geomorphology	Geology
Geochemistry, Mineralogy-	Physical Geography
Petrology	Structural Geology
Geophysics	and Geomechanics

### MINOR SUBJECTS

The program of graduate study in the Field of Geological Sciences is designed to give broad training in both the field and laboratory. Candidates for advanced degrees will take one (Master's) or two (doctorate) minor subjects outside of the Field of Geological Sciences.

Minor subjects may be chosen from many fields, such as agronomy, botany, engineering, chemistry, mathematics, physics, materials science, water resources, zoology, and biological sciences, or nonscientific fields.

All of the major subjects in the Field of Geological Sciences can also be taken as minor subjects by students in other fields completing a minor in Geological Sciences. Besides these, other minor subjects in the Field are sedimentation, Pleistocene geology, water resources, and geological oceanography.

Graduate work in Geological Sciences may include investigation under approved direction in localities away from Ithaca and the northeastern states. A brochure about graduate work in Geological Sciences may be obtained by writing to the Field Representative.

**ADMISSION REQUIREMENTS.** Candidates with a major in this Field will be expected to offer for admission an A.B. degree or its equivalent. Students with undergraduate majors other than geology, such as physical sciences or engineering, may be admitted with the expectation that deficiencies in the Geological Sciences at the undergraduate level will be rectified soon after admission, so that all graduate students in this program will then have the equivalent of the course work of a Cornell undergraduate major in Geological Sciences.

Applicants for graduate study in Geological Sciences should take the Graduate Record Examination Aptitude Test and Advanced Test in Geology in sufficient time to permit inclusion of the results in the application for admission to the Graduate School.

**LANGUAGE REQUIREMENTS.** *Master's:* proficiency in one of the following: French, German, or Russian to be established before the completion of the second residence unit. *Doctorate:* proficiency in two of the following: French, German, Russian. Both must be established before the candidate will be allowed to schedule the Final Examination on his thesis.

Language examinations will be administered by the Graduate Language Board.

**EXAMINATIONS.** The Special Committee conducts all examinations required for the degree. At the time of entrance to the Field, a general examination covering the candidate's preparatory training may be given by the faculty to assist in planning a program of study.

*Master's degree:* final examination which consists of a comprehensive on the major and minor fields and the thesis. *Doctoral degree:* a qualifying examination is required in addition to the examinations required by the Graduate School. The qualifying examination will determine the applicant's fitness for undertaking advanced studies and will enable the Special Committee to plan a program which will make the student familiar with the requisite knowledge in his chosen area. It must be taken before the end of the second semester in residence. The Graduate School requires a comprehensive Admission to Candidacy Examination and a Final Examination covering the thesis.

**DEGREE REQUIREMENTS.** *Master's degree:* a minimum of two residence units; proficiency in one language; one minor outside Geological Sciences; submission of thesis and final examination. *Ph.D. degree:* a minimum of six residence units; proficiency in two languages; a comprehensive Admission to Candidacy Examination on major and two minors outside Geological Sciences; submission of dissertation and defense.

**MASTER OF SCIENCE FOR TEACHERS.** A Master of Science for Teachers (Earth Science) program is offered in conjunction with the Department of Science Education; no thesis is required.

**MASTER OF ENGINEERING.** Program is offered in conjunction with the College of Engineering; no thesis is required. A major in an engineering subject is combined with a sequence of courses in Geological Sciences.

## Research and Study Opportunities

The Ithaca region is particularly suited for research in stratigraphy, paleontology, geomorphology, and glacial geology. The nearby Adirondack area is a classic one for studies in metamorphic and igneous petrology. Research

projects in structural geology, geomechanics, engineering geology, and hydrogeology are available at field sites in western as well as northeastern states, as are projects in mineral deposits, physical geography, and areal geology. The laboratories of the department contain standard as well as specialized equipment. Through the cooperating faculty of other departments on campus, every type of special and advanced equipment is available. The well-equipped laboratories and the exceptional libraries provide excellent opportunities for graduate research.

The department owns outstanding reference collections for teaching and research, such as: the Benjamin Silliman, Jr. Collection of minerals acquired in 1868; suites of ores and host rocks from worldwide mining districts; and extensive invertebrate fossils of Paleozoic, Mesozoic, and Cenozoic from throughout the world; as well as the major collection of Recent mollusks (10,000 species) assembled by Wesley Newcomb and purchased in 1868 by Ezra Cornell.

The Paleontological Research Institution, a private research organization, is near the campus, and its facilities are available to the specialized investigator.

The department has a cooperating agreement with the Museum of Northern Arizona at Flagstaff, for accommodating research projects and investigators. Every conceivable geologic condition and feature is available for study in the region, which constitutes an unusual field setting. The Committee for Labrador Studies has been pursuing research in Labrador for forty years, and projects are in progress on field mapping, glacial geology, and petrography.

For summer research grants in geological science at the Museum of Northern Arizona and elsewhere (after one year at Cornell), consult the Field Representative.

## Interdisciplinary Studies

Graduate studies may be pursued in many of the specialized interdisciplinary areas of geological sciences as either a major or a minor at the Master's and doctorate levels, such as:

**OCEANOGRAPHY.** Oceanography and marine ecology are offered in cooperation with the Division of Biological Sciences and the Department of Conservation. Research projects are in progress in the Long Island coastal areas, and cooperative research is provided with the Woods Hole Oceanographic Institute, Isle of Shoals Station, University of New Hampshire, and the Mote Marine Laboratory, Sarasota, Florida.

**WATER RESOURCES.** Water resources is available through the University-wide Water Resources Center with programs of study to meet individual requirements in the physical, biological, and social sciences, and in engineering.

A professional scientific hydrology program is available for majors in geohydrology in the Geological Sciences.

**APPLIED BRANCHES.** Programs of study are available in the following branches of applied geological science: mining geology-mineral deposits, petroleum geology, hydrogeology and geohydrology, and engineering geology. The major in a branch of applied geological science has two minors outside the department, in such subjects as soil science, hydraulics, water resources, soil mechanics, materials engineering, mathematics, chemistry, physics, economics, and regional planning.

**COOPERATING FACULTY.** Many additional interdisciplinary courses are offered by faculty in other departments or divisions such as: paleobotany, ecology-systematics, biogeochemistry, limnology, soil genesis, soil mineralogy, aerial photo analysis, regional planning, hydraulics and hydrology, and materials science and engineering.

## Financial Aid

There are nine graduate teaching fellowships available in the Field of Geological Sciences. Appointments are for the academic year to supervise laboratory sections and other duties for approximately fifteen hours per week. The stipend ranges from \$2,200 to \$2,500, plus scholarships covering tuition and fees (\$2,200) for a total value of \$4,400 to \$4,700. Full residence credit is given for advanced degrees.

In addition, teaching fellows who are doctoral candidates are eligible for special summer awards of up to \$500 to pursue their research projects.

The Eleanor Tatum Long Fellowship, restricted to research in the subject of structural geology and geomechanics, for either Master's or doctoral candidates, carries a stipend of \$2,100 and a scholarship covering tuition and fees (\$2,200) for a total value of \$4,300.

The department has several special endowments which, at the discretion of the staff, may be used to assist graduate students in their research and field work.

Research assistantships are available in certain cases from individual faculty research grants or contracts, either during the summer or the academic year.

The Graduate School administers a number of scholarships and fellowships. Awards are based on scholastic ability and promise of achievement as a graduate student. Besides the Cornell-supported awards, financial aid is offered by foundations and national agencies, e.g., NSF, NDEA, NASA, NIH, and by the State of New York.

## Courses

(Students should check this tentative listing with department for any changes).

### GEOGRAPHY, PHYSICAL

#### 312. GEOGRAPHY OF ANGLO-AMERICA

Spring term. Credit four hours. Prerequisite: Geography 111 or Geology 102. Lectures, M W F 9:05 and additional assigned problems. Staff. Alternate-year course.

The geographic provinces of Anglo-America, their geomorphic expression, climates, resources, development, and interrelationships.

#### [314. CONTINENTAL GEOGRAPHY]

Spring term. Credit four hours. Prerequisite: Geography 111 or Geology 102. Lectures, M W F 9:05 and additional assigned problems. Staff. Alternate-year course. Not offered in 1969-70.

Physical geography, regional climatology, land use, and natural resources of a selected continent or region.



**610. SPECIAL WORK**

Throughout the year. Credit two hours a term. Prerequisite: consent of the instructor. Staff.

Special or original investigations in physical geography on the graduate level.

**GENERAL GEOLOGY****Physical Processes****322. STRUCTURAL GEOLOGY-TECTONICS**

Spring term. Credit four hours. Prerequisites: Geology 102 (or 203) and 351; 352 recommended. Lectures, M W 11:15. Laboratory, M 2-4:25, and additional assigned problems. Field trips. Mr. Kiersch.

Nature, origin, and recognition of geologic structures. Behavior of geologic materials, stresses, geomechanical and tectonic principles applied to the solution of geologic problems. Analysis of structural features by three-dimensional methods.

**421. SEDIMENTATION**

Fall term. Credit four hours. Prerequisite: Geology 352; Geology 441 recommended. Lectures, M W 9:05. Laboratory, T 2-4:25, and additional laboratory work. Field trips. Messrs. Philbrick and Kiersch. Alternate-year course.

Source materials, mechanics of transport and dispersal, depositional environments, lithification and diagenesis of sediments. Analysis of common problems in applied fields due to these phenomena.

**441. GEOMORPHOLOGY**

Fall term. Credit four hours. Prerequisite: Geology 102. Lectures, T Th 9:05. Laboratory, T 2-4:25, and additional assigned problems. Mr. Bloom.

Description and interpretation of land forms in terms of structure, process, and stage.

**444. GEOLOGICAL OCEANOGRAPHY**

Spring term. Credit three hours. Prerequisite: Geology 102 or Biological Sciences 461. Lectures, M W F 9:05. Field trips. Mr. Bloom.

Shoreline erosion, transportation and deposition; origin and structure of continental shelves and ocean basins. Geologic processes and geomorphic development in the marine environment.

**522. FLUVIAL PROCESSES (or Civil Engr. 2333)**

Spring term. Credit two hours. Prerequisite: consent of the instructor. Seminar, hours to be arranged. Field trips. Course offered jointly with the School of Civil Engineering on demand. Mr. Kiersch.

The common problems of fluvial processes, hydraulics, and sediment transport are studied along with the appropriate analytical methods and experimental techniques.

**542. GLACIAL AND PLEISTOCENE GEOLOGY**

Spring term. Credit three hours. Prerequisite: Geology 441 or consent of the instructor. Lectures, T Th 9:05. Laboratory, T 2-4:25. Several Saturday field trips. Mr. Bloom.

Glacial processes and deposits and the stratigraphy of the Pleistocene.

## GEOCHEMISTRY

### Mineral Materials and Processes

#### 351. MINERALOGY

Fall term. Credit four hours. Prerequisites: Geology 102 and Chemistry 108. Lectures, M 10:10. Laboratory, W F 2-4:25. Mr. Chang.

Crystallography, crystal chemistry, and systematic mineralogy of the ore and rock-forming minerals.

#### 352. PETROLOGY

Spring term. Credit four hours. Prerequisite: Geology 351. Lectures, M F 10:10. Laboratory, Th 2-4:25, and additional assigned problems. Staff.

Composition, classification, and origin of igneous, sedimentary and metamorphic rocks.

#### 451. OPTICAL MINERALOGY

Fall term. Credit four hours. Prerequisite: Geology 351. Lecture, T Th 11:15. Laboratory, F S 9:05-12:20, and additional assigned problems. Staff.

Optical properties of crystals and their application to the determination and study of common rock-forming minerals with the petrographic microscope.

#### 452. OPTICAL PETROGRAPHY

Spring term. Credit four hours. Prerequisites: Geology 352 and 451. Lecture, T Th 11:15. Laboratory, F S 9:05-12:20, and additional assigned problems. Staff.

Description, classification and determination of the origin of igneous, metamorphic, and sedimentary rocks by the use of the petrographic microscope.

#### 551. GEOCHEMISTRY

Fall term. Credit three hours. Prerequisite: Geology 352. Lectures, M W F 8. Mr. Chang.

Distribution of major and minor elements in the earth, geochemical cycles of the elements, and chemistry of weathering and petrogenesis.

#### 554. X-RAY ANALYSIS

Spring term. Credit two hours. Prerequisite: Geology 352 or consent of the instructor. Lecture, W 12:20. Laboratory, F 2-4:25. Mr. Chang.

Theory and use of x-ray diffraction and spectroscopy in identification and analysis of minerals, rocks, and soils.

#### 653. ADVANCED PETROLOGY

Fall term. Credit three hours. Prerequisite: Geology 452. Lectures, T Th 9:05. Laboratory, Th 2-4:25. Staff.

Methods of study, geologic and geochemical relationships, and petrogenesis of igneous and metamorphic rocks.

#### 656. ADVANCED MINERALOGY

Spring term. Credit three hours. Prerequisites: Geology 452 and 554. Lectures, T Th 9:05. Laboratory, Th 2-4:25. Mr. Chang.

A theoretical treatment of the crystal chemistry and thermodynamics of rock-forming minerals.

## Mineral Deposits

### 461. MINERAL DEPOSITS: METALS

Fall term. Credit four hours. Prerequisite: Geology 352. Lectures, M W F 10:10. Laboratory, F 2-4:25. Field trips. Mr. Clark.

Principles and processes involved in the formation of mineral deposits. Modes of occurrence, origin, distribution, and utilization of the major, rare, and minor metals.

### 462. MINERAL DEPOSITS: NONMETALS

Spring term. Credit four hours. Prerequisite: Geology 461 or consent of the instructor. Lectures, M W F 10:10. Laboratory, F 2-4:25. Field trips. Mr. Clark.

Properties, occurrence, associations, distribution, and economic utilization of the industrial minerals and rocks.

### [563. ORE MICROSCOPY]

Fall term. Credit two hours. Prerequisites: Geology 451 and 461. Laboratory, F S 7:30-9:55 A.M. Alternate-year course. Not offered in 1969-70. Mr. Clark.

Identification of ore-minerals in polished sections which reflect light by etching and microchemical reactions; study and interpretation of mineral relationships.

## GEOPHYSICS

### 581. EXPLORATION GEOPHYSICS

Fall term. Credit three hours. Prerequisites: Physics 208, Geology 102 or 203; Geology 322 is recommended. Lectures, T Th 9:05. Laboratory, S 10:10-12:35, and assigned problems. Mr. Clark and staff. Alternate-year course.

Elementary theory and interpretation of data from exploration geophysical methods. Environmental geology and selection of techniques for important applied areas.

### 583. PHYSICS OF THE EARTH

Fall term. Credit three hours. Prerequisites: Geology 322, Math 112, Physics 208. Lectures and Laboratory to be arranged. Staff.

Theory and field measurements of the earth's gravitational, magnetic, seismic, electrical, thermal, and radioactive properties.

### 584. SEISMOLOGY

Spring term. Credit three hours. Prerequisite: Geology 583. Lectures and Laboratory to be arranged. Staff.

Theory of stress and strain, seismic wave propagation, earthquake studies, and observational seismology.

### 586. SEMINAR IN ROCK DEFORMATION

Spring term. Credit two hours. Prerequisites: Geology 533 and 583. Lectures to be arranged. Staff.

Review of stress analysis and behavior of materials, both the rock mass and sample. Fundamentals of deformation pertaining to the crustal rocks and the problems of applied geological science.

## APPLIED GEOLOGICAL SCIENCE

### 532. HYDROGEOLOGY

Spring term. Credit three hours. Prerequisites: Geology 322, 352; 441 is recom-

mended. Lectures, M W 9:05. Laboratory, T 2-4:25 and field trips. Mr. Philbrick. Alternate-year course.

Hydrologic cycle and water provinces; occurrence, movement, quantity, and chemical quality of ground water in porous media. Water resources development.

### 533. ENGINEERING GEOLOGY—THEORY AND ENVIRONMENTS

Fall term. Credit three hours. Prerequisites: Geology 322, 352; Geology 441 is recommended. Lectures, M W 11:15. Laboratory, M 2-4:25 and field trips. Mr. Kiersch.

Advanced study of the physical phenomena and rock properties of special importance from the planning through the operation stages of engineering works; includes underground fluids, subsidence, gravity movement, seismicity, geomechanics and stresses, rock mechanics, weathering, and geologic materials of construction. Analysis of geologic problems encountered in practice; predicting the influence of natural and man-made environmental factors.

### 535. ENGINEERING GEOLOGY—PRACTICE

Fall term. Credit three hours. Prerequisites: Geology 533 or 322-352 and 441. Lectures, M W 9:05. Laboratory, T 2-4:25 and field trips. Mr. Philbrick. Alternate-year course.

Application of geological principles in the planning-design, construction, and operation of engineering works. Case histories, analysis, and evaluation of physical environmental factors, remedial treatment, and reports.

### 561. FUNDAMENTALS OF MINING GEOLOGY

Fall term. Credit three hours. Prerequisites: Geology 461 and 462. Lectures, M W F 10:10. Assigned problems. Field trips. Mr. Clark. Alternate-year course.

Principles of geological, geophysical, and geochemical techniques used in mineral exploration. Mining geology, guides to ore, mining methods.

### 562. ECONOMICS OF MINERAL DEPOSITS

Spring term. Credit three hours. Prerequisites: Geology 461 and 462; 561 is recommended. M W F 10:10. Assigned problems. Mr. Clark. Alternate-year course.

Sampling and ore estimation. Cutoff, grade, tonnage, and economic factors related to mining and mineral marketing. Financial calculations and procedures used in mineral property valuation.

### 582. EXPLORATION GEOLOGY

Spring term. Credit three hours. Recommended for all graduate students in geological sciences. Prerequisites: graduate standing and field geology. Lectures, M W 9:05. Laboratory, W 2-4:25. Messrs. Philbrick and Kiersch. Alternate-year course.

Methods of exploration and appraisal of geologic data from both field and laboratory investigations. Assessment of environmental geology and the presentation of direct and indirect information for professional purposes and applied fields.

## GEOBIOLOGY

### Paleontology and Stratigraphy

#### 471. INVERTEBRATE PALEONTOLOGY

Fall term. Credit four hours. Prerequisites: Geology 102, and, if possible,

invertebrate zoology. For those interested in fossil evidence of the development of organisms. Lectures, T Th 10:10. Laboratory, W Th 2-4:25. Mr. Wells.  
Paleobiology and classification of important fossil invertebrates.

#### 472. PRINCIPLES OF HISTORIC GEOLOGY

Spring term. Credit four hours. Prerequisites: Geology 322 and 471. Lectures, T Th 10:10. Laboratory, W 2-4:25, and additional assigned problems. Mr. Wells.

Application of geologic principles to interpretation of earth history; development of the geologic column, geochronology and geochronometry; correlation and the zone concept; sedimentary environments and provinces; geosynclines and platforms; problems of the pre-Cambrian and continental evolution.

#### 571. STRATIGRAPHY: PALEOZOIC

Fall term. Credit three hours. Prerequisite: Geology 472. Lectures, T Th 9:05 and W 7:30 P.M. Mr. Wells. Alternate-year course.

Principles of stratigraphy developed by detailed study of selected American and European systemic examples.

#### 572. STRATIGRAPHY: MESOZOIC AND CENOZOIC

Spring term. Credit three hours. Prerequisite: Geology 472. Lectures, T W Th 9:05. Mr. Wells.

Principles of stratigraphy developed by detailed study of selected American and European systemic examples.

#### 671. MICROPALEONTOLOGY

Spring term. Credit two hours. Prerequisites: Geology 472 and 572. Lecture, W 9:05. Laboratory, W 2-4:25, and additional assigned problems. Staff.

Microfossils, chiefly Foraminifera.

#### 672. STRATIGRAPHY OF NEW YORK STATE

Spring term. Credit three hours. Prerequisite: Geology 571. Lectures, T Th 12:20 early in the term, followed by all-day and weekend field trips. Mr. Wells. Alternate-year course.

The classic Paleozoic sections of New York studied through lectures, readings, and field observation.

### SEMINARS AND SPECIAL WORK

#### 490. SENIOR THESIS

Either term. Credit one hour. Staff.

#### GEOLOGY 673. SEMINAR IN THE HISTORY OF GEOLOGY

Fall term. Credit two hours. Hours to be arranged. Mr. Wells.

Part of the graduate program in the history of science.

#### SEMINAR IN GEOLOGICAL SCIENCES

Each term. No credit. For majors and required of graduate students, but open to all who are interested. T 4:45. Staff and visiting lecturers.

Reports and discussion of current research in the geological sciences.

#### 690. SPECIAL WORK

Throughout the year. Credit two hours a term. Prerequisite: consent of the instructor. Staff.

Advanced work on original investigations in geological sciences on the graduate level.

## 132 MATERIALS SCIENCE AND ENGINEERING

690-a. Analytical geochemistry, crystallography, and mineralogy. Mr. Chang.

690-b. Volcanic petrology and geochemistry.

690-c. Coastal geomorphology and Pleistocene geology. Mr. Bloom.

690-d. Engineering geology, geomechanics, and hydrogeology. Mr. Kiersch.

690-e. Seismology, crustal and marine geophysics, heat flow. Staff.

690-f. Invertebrate paleontology and paleoecology. Mr. Wells.

690-g. Sedimentology and primary structures.

Fall term. Credit one hour. Hours to be arranged. A special lecture seminar by Mr. E. D. McKee.

690-h. Physical and engineering geology, water resources. Mr. Philbrick.

690-i. Mineral deposits and resources, exploration geophysics. Mr. Clark.

## MATERIALS SCIENCE AND ENGINEERING

Faculty: Robert W. Balluffi, Boris W. Batterman, John M. Blakely, Malcolm S. Burton, Paul S. Ho, Joseph O. Jeffrey, Herbert H. Johnson, Edward J. Kramer, Che-Yu Li, Walter S. Owen, Thor N. Rhodin, Arthur L. Ruoff, Henri S. Sack, Stephen L. Sass, Eraldus Scala, David N. Seidman, Benjamin M. Siegel, John Silcox, Floyd O. Slate, George V. Smith, Anthony Taylor, Watt W. Webb.

Field Representative: Che-Yu Li, 329 Bard Hall.

### MAJOR SUBJECTS

Materials Science

Materials and Metallurgical  
Engineering

### MINOR SUBJECTS

Materials Science

Materials and Metallurgical  
Engineering

**ADMISSIONS REQUIREMENTS.** Graduates from any undergraduate engineering or physical science program will be accepted if they have demonstrated marked competence in the basic parts of their studies and show competence, in general, as graduate students. Applicants who lack some prerequisites for graduate courses recommended by the Field, but are otherwise qualified, will be allowed to remedy the deficiency by taking undergraduate courses while enrolled as graduate students.

It is recommended, but not required, that applicants present the results of the Graduate Record Examination with their applications.

**LANGUAGE REQUIREMENTS.** There are no language requirements for the M.S. or Ph.D. degrees.

**TEACHING REQUIREMENT.** The Field considers teaching experience to be an important part of academic training of doctoral candidates and hence makes such experience a requirement for all qualified students.

**EXAMINATIONS.** All examinations required for a degree are administered and reported by the candidate's Special Committee. The examinations may be oral, or written and oral. In accordance with Graduate School legislation, a

comprehensive examination is required for admission to Ph.D. candidacy. A thesis examination is given upon submission of the Ph.D. thesis.

For the M.S. degree, an examination is required at the time of submission of the M.S. thesis. At the discretion of the Special Committee, this examination may consider the thesis, or the thesis and course work. Under suitable circumstances, the Master's final examination and the Admission to Candidacy Examination may be combined.

## Research and Study Opportunities

Graduate programs in Materials Science and Engineering lead to careers either in research and development, or in engineering application of materials. This is accomplished through comprehensive and integrated course programs, participation in formal and informal research seminars, thesis research, and not infrequently in informal discussions.

The spectrum of current research programs in the Field is very broad, ranging from problems of immediate technological interest, such as crack propagation in high strength steels, to considerably more basic investigations in such areas as point defects and superconductivity.

Current research in the Field includes the following:

1. Mechanical behavior: interstitial and substitutional solid solutions, crack formation and propagation, embrittlement phenomena, fatigue, composite materials, anelasticity.
2. Imperfections in solids: point defects, dislocation mechanics, defect interactions, radiation damage, substructure.
3. Phase transformations: crystal growth, precipitation, martensite, alloy steels, superconductivity, solidification, phase decomposition during sintering.
4. Surface structure and reactions: solid-liquid and solid-gas interfaces, field ion microscopy, surface diffusion, low energy electron diffraction, crystal nucleation.
5. High temperature materials: structure and properties of pyrolytic graphite, composite materials, refractory metals and alloys, complex compounds, sintering of ceramics.
6. High pressure studies: creep, diffusion, elastic constants, electrical properties.
7. Electrical and magnetic behavior: superconductivity, semiconductors, NMR, conduction in oxides, magnetic domain wall motion, photoconductivity.
8. Development of advanced experimental techniques: electron microscopy, x ray, high pressure, crystal growing, purification methods.

More detailed information about course programs and research areas is available upon request.

A strong catalyst for the materials research activities at Cornell has been provided by the Materials Science Center, which is supported by the Advanced Research Projects Agency of the U. S. Government, and with which most of the Field faculty are affiliated. The MSC provides substantial financial assistance for graduate students through research assistantships, new equipment for approved thesis research projects, and in some cases, technical assistance in performing routine measurements.

A most important contribution of MSC has been the creation and maintenance of central research facilities which are used by both faculty and graduate students. Each central facility is directed by a senior staff member and staffed by trained technicians. Faculty and students receive expert guidance and assistance from these facilities, which include laboratories for

materials preparation, metallography, x-ray diffraction, electron microscopy, electronics, high pressure, low temperature, chemical analysis, irradiation and non-metallic crystal growth.

## Professional Degree

In addition to the M.S. and Ph.D. programs, the Field also offers the professional degree of Master of Engineering (Materials). The professional program, available to students who have demonstrated suitable proficiency in the area of materials and metallurgy in earning their Bachelor's degree, provides advanced courses designed to enlarge the student's preparation for a career in professional engineering with less emphasis on achievement in research. The Master of Engineering program is administered by the Engineering Division of the Graduate School. (See page 28.)

## Courses

### GRADUATE CORE PROGRAM: MATERIALS SCIENCE AND ENGINEERING

#### 6601. TOPICS IN THERMODYNAMICS AND KINETICS

Fall term. Credit three hours.

Generalization of thermodynamics to include nonchemical forms of energy. Statistical nature of entropy. Phase stability. Defect equilibria. Thermodynamics of solutions, surfaces, and interfaces. Reaction kinetics. Diffusion. At the level of Slater, *Introduction to Chemical Physics*; Guggenheim, *Thermodynamics*.

#### 6602. PHASE TRANSFORMATIONS

Spring term. Credit three hours.

Interfaces between phases. Nucleation theory. Growth theory. Formal theory of nucleation and growth transformations. Spinodal decomposition. Diffusionless transformations. Applications of the theory to specific changes in real materials. At the level of Christian, *Theory of Phase Transformations in Metals and Alloys*.

#### 6603. CRYSTAL MECHANICS

Fall term. Credit three hours.

Crystal symmetry. Vector fields and tensor fields. Lattice deformation and fault crystallography. Reversible tensor properties of crystals. Relationships between different tensor properties. Crystal elasticity, elastic waves and polymer elasticity. Lattice dynamics. Thermophysical properties. Irreversible tensor properties. Coupling of transport phenomena. Higher order effects. At the level of Nye, *Physical Properties of Crystals*; Born and Huang, *Dynamical Theory of Crystal Lattices*; and Smith, *Wave Mechanics of Crystalline Solids*.

#### 6604. DISLOCATIONS

Fall term. Credit three hours.

Review of geometrical and strain energy aspects of dislocation theory. Experimental evidence for dislocations. Dislocation strain and stress fields and associated strain energy. Interactions with applied stresses and with other dislocations. Jogs, point defects and climb. Dislocation sources. Crystallographic



aspects such as stacking faults and partial dislocations in specific crystal structures. Grain boundaries. At the level of Friedel, *Dislocations* and Nabarro, *Theory of Crystal Dislocations*.

#### 6605. ELECTRICAL AND MAGNETIC PROPERTIES OF ENGINEERING MATERIALS

Fall term. Credit three hours. Prerequisite: Physics 454 or consent of the instructor.

Electrical properties of semiconductors. Metallic alloys. Ferromagnetic materials. Superconductivity. Optical and dielectric properties of insulators and semiconductors. Ferrites. At the level of Kittel, *Introduction to Solid State Physics*; Chikazumi, *Physics of Magnetism*; Lynton, *Superconductivity*; Livingston and Schadler, *The Effect of Metallurgical Variables on Superconductivity Properties*.

#### 6606. MECHANICAL BEHAVIOR OF MATERIALS

Spring term. Credit three hours.

Geometry of slip in single crystals. Strain hardening. Dislocation dynamical treatment of yield and flow. Interaction of interstitial solute atoms with dislocations. Solution hardening. Two-phase hardening. Time dependent deformation. Dislocation models for cleavage of crystals. At the level of review articles in *Progress in Materials Science* and various conference reports.

#### 6611. PRINCIPLES OF DIFFRACTION

Fall term. Credit three hours. Offered jointly with Applied Physics (8211).

A broad introduction to diffraction phenomena applied to solid state problems. Production of neutrons and x rays. Scattering and absorption of neutrons, electrons and x-ray beams. Diffraction from two- and three-dimensional periodic lattices. Crystal symmetry, Fourier representation of scattering centers and the effect of thermal vibrations on scattering. Phonon information from diffuse x-ray and neutron scattering as well as Bragg reflections. Standard crystallographic techniques for single crystals and powders. Diffraction from almost periodic structures, surface layers, gases and amorphous materials. A survey of dynamical diffraction from perfect and imperfect lattices. Techniques for imaging structural defects. Selected experiments illustrating diffraction effects.

## Professional Master's Degree

#### 6503. MATERIALS SELECTION AND USE

Fall term. Credit three hours. Three lectures. Prerequisite: 6032.

Metallurgical and mechanical factors governing the selection of metals for various services. Analysis of service requirements and the selection and fabrication of metals to fulfill such requirements; analysis of service failures of metals and remedies for such failures; and study of the merits and limitations of materials applications in existing products and equipment.

#### 6553-6554. PROJECT

Fall and spring terms. Credit three hours.

Research on a specific problems in materials or metallurgical engineering.

#### 6555. MATERIALS PROCESSING

Spring term. Credit three hours. Three lectures.

A course on the principles of materials processing including both metallic

and nonmetallic materials. The control of the properties of materials and various solutions to engineering problems of shaping, making, and treating practice are stressed.

## Other Graduate Courses

### 6612. SELECTED TOPICS IN DIFFRACTION

Spring term. Credit three hours. Three lectures. Prerequisite: 6611. Offered jointly with Applied Physics (8212).

The Ewald-von Laue dynamical theory applied to x-ray and high energy electron diffraction in solids. Thermal scattering and measurement of phonon dispersion, frequency spectrum, interatomic force constants, Debye temperatures and vibrational amplitudes. Diffuse scattering, short- and long-range order, precipitation in solids, point defects.

### 6762. PHYSICS OF SOLID SURFACES

Spring term. Credit three hours. Three lectures. Offered jointly with Applied Physics (8262).

Equilibrium thermodynamics and statistical mechanics of interfaces. Diffuse interfaces, crystal surfaces, anisotropy and orientation dependence of surface properties, Wulff diagrams. Atomic structure of surfaces in equilibrium. Surface fields, dipoles and defects in insulators. Electronic and vibrational properties of surfaces. Surface barriers and work functions, surface vibrational and electronic states. Kinetic processes at surfaces. Mass and charge transport in the surface region. Condensation and evaporation processes. Experimental techniques: discussion of LEED, FIM, FEM, etc. Materials drawn from research papers and various reviews articles such as *Progress in Materials Science*, *Advances in Chemistry*, *Solid State Physics*, and specialized texts such as Many, Goldstein and Grover, *Semiconductor Surfaces* and Kaminsky, *Atomic and Ionic Impact Phenomena*.

### 6764. FRACTURE OF MATERIALS

Spring term. Credit three hours. Three lectures.

Mechanics of fracture. Griffith theory. Crack tip stresses and strains. Crack tip plasticity. Macroscopic aspects of fracture in crystalline and non-crystalline materials. Dislocation models. Void growth. Special topics such as fatigue, environment and fracture, fracture testing. Materials from various conference reports; Tetelman and McEvily, *Fracture of Structural Materials* and Kelly, *Strong Solids*.

### 6765. AMORPHOUS AND SEMICRYSTALLINE MATERIALS

Fall term. Credit three hours. Three lectures.

Topics related to the science of the amorphous state selected from within the following general areas: structure of liquids and polymers, rheology of elastomers and glasses, electrical, thermal and optical properties of amorphous materials. Presented at the level of J. D. Mackenzie, *Modern Aspects of the Vitreous State*; Frechette, *Noncrystalline Solids*; Treloar, *The Physics of Rubberlike Elasticity*.

### 6766. MATERIALS SCIENCE SEMINAR

Fall term. Credit two hours. One seminar period.

Topics selected from current research interests of the faculty.

## 6873. MATERIALS SCIENCE FOR ENGINEERS

Fall term. Credit three hours. Three lectures.

Structure of crystals. Crystal lattice properties. Crystal defects (point, line, planar). Thermodynamics of solids. Diffusion and kinetics (emphasis on defect annealing, e.g., polygonization, recrystallization, grain growth, point defect recovery, etc.). Mechanical properties (role of crystal defects in plastic deformation, creep, fracture). Topics in radiation damage including defect productions, radiation damage annealing and effect of damage on physical properties.

## MATHEMATICS

Faculty: James B. Ax, Michael S. Balch, Jon Beck, Israel Berstein, James H. Bramble, Lawrence D. Brown, Stephen U. Chase, Marshall M. Cohen, Clifford J. Earle, James Eells, Jr., William G. Faris, Roger H. Farrell, Michael E. Fisher, Wolfgang H. J. Fuchs, Solomon Garfunkel, Leonard Gross, Richard A. Hager, Richard S. Hamilton, David W. Henderson, Carl S. Herz, Peter J. Hilton, Arun Jategaonkar, Peter J. Kahn, Harry Kesten, Jack Kiefer, Anthony W. Knapp, Richard B. Lavine, Simon A. Levin, Stephen Lichtenbaum, G. Roger Livesay, Michael D. Morley, Anil Nerode, Paul Olum, Lawrence E. Payne, Richard A. Platek, George S. Rinchart, Alex Rosenberg, Oscar S. Rothaus, Stephen H. Schanuel, Alfred H. Schatz, Robert B. Schneider, Leonard S. Silver, Frank L. Spitzer, Moss E. Sweedler, Robert J. Walker, Hsien-Chung Wang, Jacob Wolfowitz.

Visiting Professors: David A. Burgess, B. W. H. Pareigis, Urs Stambach, Tadashi Ueno.

Field Representative: Alex Rosenberg, 124 White Hall.

## MAJOR AND MINOR SUBJECTS

Algebra  
Analysis

Geometry  
Mathematics

Prerequisites for admission are a knowledge of advanced calculus (including both theoretical and applied points of view) and modern algebra.

The Field of Mathematics has set the following language requirements: none for the Master's degree; a reading knowledge of German or Russian for the Ph.D. degree. There is no formal French requirement, but books and papers in that language will be freely used in all graduate courses and students can expect to be called upon to read French mathematical texts.

The Field of Mathematics requires teaching experience of all graduate students as part of the requirements for an academic degree.

Candidates for the Master's degree are expected to obtain some understanding of mathematical thought, ordinarily by taking about twenty-four hours of courses at the graduate level. Qualifications for the Doctor's degree include a broad acquaintance with the basic subjects of present-day mathematics plus a demonstration of ability to do research in one or more branches of mathematics.

A booklet entitled *Graduate Work in Mathematics at Cornell* may be obtained by writing to the Chairman, Department of Mathematics, White Hall. The booklet contains additional information about graduate work, thesis and examination requirements, and research in mathematics for the entering graduate student.

All of the three major subdivisions of mathematics (algebra, analysis, and geometry) are well represented at Cornell. Moreover, the department is also very strong in logic, probability, and statistics. A detailed listing of the research interests of the members of the faculty will be sent to all who request the booklet, *Graduate Work in Mathematics*, referred to above.

## Courses

In all 600-level courses, as well as 502, the final grades will be only S or U.

All listings are tentative; students should check with the departmental office for definite listings, times, places, etc.

The advanced courses at the 500 and 600 level shown below were offered during 1968-69. In 1969-70, about the same number of advanced courses will be given; they will be selected from those offered in 1968-69 and the bracketed courses, which were not offered in 1968-69.

## GENERAL

### 502. GRADUATE PROSEMINAR

Spring term. Credit four hours. Prerequisite: candidacy for an advanced degree with a major in mathematics. M W F 2:30.

Presentation by students of material in mathematical literature. Required of all graduate students majoring in mathematics.

## APPLIED MATHEMATICS AND DIFFERENTIAL EQUATIONS

### 315. HIGHER CALCULUS

Fall term. Credit three hours. Prerequisite: 213 or 293. T Th S 10:10.

Intended for students who have had only three semesters of calculus. It does not prepare a student for 415-416, and will not meet the needs of those graduate students whose work requires really serious application of mathematical methods.

Vector analysis. Ordinary and partial differential equations. Fourier series. Special functions. Laplace transforms. Emphasis is placed on a wide range of formal applications of the calculus rather than on the logical development.

### 415-416. MATHEMATICAL METHODS IN PHYSICS

Throughout the year. Credit four hours a term. Undergraduates will be admitted only with the consent of the instructor. First term prerequisite to second. T W Th F 12:20. Mr. Fuchs.

Intended for graduate students in physics or related fields who have had a strong advanced calculus course and at least two years of general physics. The course goes very quickly, covering in two semesters slightly more than 421-422-423.

Lectures and problems designed to give a working knowledge of the principal mathematical methods used in advanced physics. Topics include a brief discussion of some basic notions: metric space, vector space, linearity, continuity, integration. Generalized functions (Schwartz distributions). Fourier series and Fourier integrals. Elementary complex variable. Saddle point method. Linear transformations in finite and in infinite-dimensional spaces. Matrices. Differential operators and integral operators, the equations and

eigenvalue problems connected with them and the special functions arising from them. Elements of group theory. The rotation group and its representations.

#### 421. APPLICABLE MATHEMATICS

Fall term. Credit four hours. Prerequisite: 222, or honors section of 294, or consent of the instructor. (Students from regular sections of 294 will be admitted upon the recommendation of the instructor of 294, provided their grades are very high and they make up the extra work.) M W F 12:20, Th 2:30.

Graduate students who need mathematics extensively in their work and who have had a solid advanced calculus course as undergraduates should take 415-416. If they have not had such an advanced calculus course, they should take 421-422-423. If their preparation is still too weak for this, they should take all or part of 221-222, followed by 421-422-423.

Theorems of Stokes, Green, Gauss, etc. Sequences and infinite series. Fourier series and orthogonal functions. Introduction to complex variables.

#### 422. APPLICABLE MATHEMATICS

Spring term. Credit four hours. Prerequisite: 421 or consent of the instructor. M W F 12:20, Th 2:30.

Continuation of complex variables. Conformal mappings. Harmonic functions. Some special functions. Differential equations. Laplace and Fourier transforms. Asymptotic expansions of functions.

#### 423. APPLICABLE MATHEMATICS

Fall term. Credit four hours. Prerequisite: 422. M W F 12:20, Th 2:30.

Linear operators and integral equations. Calculus of variations. Application to eigenvalue problems. Green's function, and treatment of special problems of mathematical physics.

#### 427-428. INTRODUCTION TO DIFFERENTIAL EQUATIONS

Throughout the year. Credit four hours a term. Prerequisite: 222 or 294 or consent of the instructor. First term prerequisite to second. M W F 1:25.

First term, ordinary differential equations covering the basic theory. Topics include uniqueness and existence theory, Sturm-Liouville theory, singular points, stability, approximation methods and applications. Second term, partial differential equations with treatments of Laplace, heat and wave equations. Topics include classification, maximum principles, uniqueness, stability, approximation methods and applications.

#### 517-518. ORDINARY DIFFERENTIAL EQUATIONS

Throughout the year. Credit four hours a term. Prerequisites: 411-412 and some acquaintance with complex variables, or consent of the instructor. First term prerequisite to second. M W F 10:10.

Existence and uniqueness. Autonomous systems, with specialization to geometric theory in two dimensions. Linear equations. Stability. Bifurcation theory. Some special functions of mathematical physics, from the viewpoint of equations in the complex domain and the two point boundary value problem.

#### 519-520. PARTIAL DIFFERENTIAL EQUATIONS

Throughout the year. Credit four hours a term. Prerequisite: some acquaintance with complex variables and advanced calculus or, with consent of the instructor, 423 or 416. First term prerequisite to second. T Th S 10:10.

Classification of partial differential equations. Questions of existence,

uniqueness, and continuity of the solutions of typical boundary value problems. The equations of Laplace and Poisson, principle of the maximum and the mean; the wave equation, heat equation.

#### 521. ELEMENTARY FUNCTIONAL ANALYSIS

Fall term. Credit four hours. Prerequisite: 415-416 or 421-422-423 or consent of the instructor. T Th S 9:05.

Elementary set theory and topology, Banach and Hilbert spaces, measure and integration, spectral theorem for bounded operators. Graduate students in mathematics should take 613 for functional analysis.

#### 522. APPLIED FUNCTIONAL ANALYSIS

Spring term. Credit four hours. Prerequisite: 521. T Th S 9:05.

Topics selected from spectral theory for unbounded operators in Hilbert space, compact operators, representations of compact groups, distributions. Applications to Fourier analysis, integral and differential equations, calculus of variations, quantum mechanics.

*Note:* Since the content of the 1969 version of 522 is quite different from that of the 1968 version, students could possibly take 522 twice with profit.

#### 619-620. ADVANCED PARTIAL DIFFERENTIAL EQUATIONS

Throughout the year. Credit four hours a term. Prerequisites: 512 and 613 or consent of instructor. Hours to be arranged.

Selected topics in partial differential equations. Selections from existence, uniqueness, and regularity results in the theories of elliptic, hyperbolic, and parabolic equations.

#### 627-628. SEMINAR IN PARTIAL DIFFERENTIAL EQUATIONS

Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor. Hours to be arranged.

### ANALYSIS

#### 411-412. INTRODUCTION TO ANALYSIS

Throughout the year. Credit four hours a term. Prerequisite: 222. T Th S 10:10. (There will be a special Honors section of this course. The instructor should be consulted.)

An introduction to the theory of functions of real variables, stressing rigorous logical development of the subject rather than technique of applications. Topics include elementary topology, the real number system, continuous and differentiable functions, integration, convergence and approximation theorems, Fourier series, calculus in several variables and differential forms.

#### 413. INTRODUCTION TO THE THEORY OF FUNCTIONS OF ONE COMPLEX VARIABLE

Spring term. Credit four hours. Prerequisite: 222 or 312. M W F 9:05. Course 411 is not a prerequisite, but some previous acquaintance with advanced calculus as presented in 411 is definitely helpful.

A rigorous introduction to complex variable theory. Intended mainly for undergraduates and for graduate students outside mathematics; graduate students in mathematics desiring a first course in complex variables should take 511-512. Complex numbers. Differential and integral calculus for functions of a complex variable including Cauchy's theorem and the calculus of residues. Elements of conformal mapping. Elements of several complex variables.

511-512. REAL AND COMPLEX ANALYSIS

Throughout the year. Credit four hours a term. Prerequisite: 412. M W F 9:05.

First term: set-theoretic preliminaries, abstract integration. Borel measures, Lebesgue measures,  $L_p$  spaces, Hilbert spaces, Banach spaces, product spaces, differentiation. Second term: Fourier transforms. Complex variables, harmonic functions, Schwarz lemma, approximation by rational functions, conformal mappings, including Riemann mapping theorem, Weierstrass- and Mittag-Leffler theorems, Jensen's formula, analytic continuation, the modular function, Picard's theorem.

515. POTENTIAL THEORY

Spring term. Credit four hours. Prerequisite: 512. Hours to be arranged.

Newtonian as well as logarithmic potential, capacity, Green's functions and the Dirichlet problem in Euclidean space. Either applications to function theory, or integral representation theorems, or some probabilistic potential theory.

611-612. SEMINAR IN ANALYSIS

Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor. Hours to be arranged.

613. FUNCTIONAL ANALYSIS

Fall term. Credit four hours. Prerequisite: 432 and 511. Hours to be arranged.

Topological vector spaces, Banach and Hilbert spaces, Banach algebras. Additional topics to be selected by instructor.

615. FOURIER ANALYSIS

Spring term. Credit four hours. Prerequisites: 500 and 512. Hours to be arranged.

Topics in Fourier analysis.

622. RIEMANN SURFACES

Fall term. Credit four hours. Prerequisite: 512; 531 is desirable. Hours to be arranged.

The notion of Riemann surface. Algebraic functions of one complex variable considered as functions defined on a closed Riemann surface. Differentials and integrals. Abel's theorem. The Riemann-Roch theorem. Uniformization.

[514. COMPLEX VARIABLE THEORY]

Spring term. Credit four hours. Prerequisite: 500 and 512.

[523. ANALYSIS ON MANIFOLDS]

Spring term. Credit four hours. Prerequisites: 500 and 512.

[528. VARIATIONAL METHODS]

Spring term. Credit four hours. Prerequisite: 413.

[617. ANALYTIC NUMBER THEORY]

One term. Credit four hours. Prerequisite: 514.

[621. MEROMORPHIC FUNCTIONS]

Fall term. Credit four hours. Prerequisite: consent of the instructor.

[623. SEVERAL COMPLEX VARIABLES]

Fall term. Credit four hours. Prerequisites: 500 and 514.

## ALGEBRA

### 431-432. INTRODUCTION TO ALGEBRA

Throughout the year. Credit four hours a term. Prerequisite: 221 or 331. First term prerequisite to second. M W F 10:10. (There will be a special Honors section of this course. The instructor should be consulted.)

A rigorous introduction to modern algebra. First term, linear algebra. Second term, introduction to algebraic systems such as groups, rings, modules and fields.

### 531-532. ALGEBRA

Throughout the year. Credit four hours a term. Prerequisite: 432. First term prerequisite to second. T Th 2:30-4.

First term: finite groups, field extensions, Galois theory, rings and algebras, tensor algebra. Second term: Wedderburn structure theorem, Brauer group, group cohomology, Ext, Dedekind domain, primary decomposition, Hilbert basis theorem, local rings. Additional topics selected by instructor.

### 549-550. LIE GROUPS AND DIFFERENTIAL GEOMETRY

Throughout the year. Credit four hours a term. Prerequisites: 500 and 531.

Differentiable manifolds. Basic properties of Lie groups and their relationship to Lie algebras. Compact Lie groups, maximal tori, the Weyl group. Theory of Lie algebras over the real and complex fields. The classical groups.

### 631-632. SEMINAR IN ALGEBRA

Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor. Hours to be arranged.

### 633. GROUP THEORY

Spring term. Credit four hours. Prerequisite: 531. Hours to be arranged.

Representations and characters of finite groups; transfer and induced representations. Applications to structure of finite groups as time permits.

### 635. THEORY OF RINGS

Spring term. Credit four hours. Prerequisites: 532 or 637. Hours to be arranged.

Local class field theory. First and second inequalities. Brauer group of algebraic number fields.

### 637. ALGEBRAIC NUMBER THEORY

Fall term. Credit four hours. Prerequisite: 532 or consent of the instructor. Hours to be arranged.

Valuations and extensions of valuations. Ideal theory. Factorization of ideals in field extensions. Finiteness of the class number. The unit theorem.

### 639. HOPF ALGEBRAS

Fall term. Credit four hours. Prerequisite: 532. Hours to be arranged.

Algebras, coalgebras and duality. The adjoint action. Structure theory of co-commutative coalgebras and Hopf algebras, including theorems of Poincaré, Birkhoff-Witt, Borel and Kostant. Theory of the integral and the generalized Maschke's theorem.



[641. HOMOLOGICAL ALGEBRA]

Fall term. Credit four hours. Prerequisite: 531.

[649. TOPOLOGICAL GROUPS]

Fall term. Credit four hours. Prerequisite: 500 and 531.

## GEOMETRY AND TOPOLOGY

### 451-452. CLASSICAL GEOMETRIES

Throughout the year. Credit four hours a term. Prerequisite: 221 or 331 or 431, which may be taken concurrently. First term prerequisite to second. T Th S 9:05.

Axiomatic methods in geometry. Foundations of Euclidean geometry. Non-Euclidean geometry, projective geometry, other geometric theories.

### 453-454. INTRODUCTION TO TOPOLOGY AND GEOMETRY

Throughout the year. Credit four hours a term. Prerequisites: 412 and 432 or consent of the instructor. M W F 11:15.

This is a new course (designed primarily for Option I Mathematics Majors) which will be somewhat experimental in its first year. It will cover topics in general and algebraic topology, differentiable manifolds, and perhaps some differential geometry.

### 500. GENERAL TOPOLOGY

Fall term. Credit four hours. Prerequisite: 412. M W F 2:30.

Topics from set theory, topological spaces, function spaces, manifolds, and topological groups. Fundamental group and covering spaces.

### 551. INTRODUCTORY ALGEBRAIC TOPOLOGY

Spring term. Credit four hours. Prerequisites: 432 and 500. M W F 10:10.

Homology and cohomology theories for complexes and spaces. Manifolds and geometric applications.

### 651-652. SEMINAR IN TOPOLOGY

Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor. Hours to be arranged.

### 653-654. ALGEBRAIC TOPOLOGY

Throughout the year. Credit four hours a term. Prerequisite: 551 or the equivalent. Hours to be arranged.

Categories and functors, exact and half exact functors, homotopy theory, cohomology operations, spectral sequences, duality, and applications.

### 657-658. ADVANCED TOPOLOGY

Throughout the year. Credit four hours a term. Prerequisites: 551 or consent of the instructor. Hours to be arranged.

A selection of advanced topics from modern algebraic, differential and geometric topology. The content of this course varies from year to year.

### [655-656. HOMOTOPY THEORY]

Throughout the year. Credit four hours a term. Prerequisite: 551.

### [659. SYMMETRIC SPACES]

Spring term. Credit four hours. Prerequisite: 549-550.

## 144 MATHEMATICS

### [661-662. SEMINAR IN GEOMETRY]

Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor.

### [663. MANIFOLDS]

Throughout the year. Credit four hours a term. Prerequisite: 551.

### [667. ALGEBRAIC GEOMETRY]

Spring term. Credit four hours. Prerequisites: 500 and 531.

## PROBABILITY AND STATISTICS

### 472. STATISTICS

Spring term. Credit four hours. Prerequisites: 371 and knowledge of linear algebra such as taught in 221. M W F 12:20. Preliminary examinations will be held at 7:30 P.M. on Feb. 19, Mar. 12, Apr. 9, May 7.

Classical and recently developed statistical procedures are discussed in a framework which emphasizes the basic principles of statistical inference and the rationale underlying the choice of these procedures in various settings. These settings include problems of estimation, hypothesis testing, large sample theory, experimental designs, sequential analysis and multiple decision problems. (See also the description of 370 in the *Announcement of the College of Arts and Sciences*, and 572.)

### 571. PROBABILITY

Fall term. Credit four hours. Prerequisite: 412; or, with consent of the instructor of 416 or 422. M W F 12:20. Examinations and make-up lectures, when necessary, will be held on Thursday evenings at 7:30 P.M.

Fundamentals. Combinatorial problems. Distribution functions in one or several dimensions. Important probability laws. Expectation, moments, and characteristic functions. Stochastic convergence and the law of large numbers. The central limit theorem.

### 572. STATISTICAL ANALYSIS

Spring term. Credit four hours. Prerequisite: 571. M W F 12:20.

Intended to furnish a rigorous introduction to mathematical statistics, this course is prerequisite to all advanced courses in statistics.

A continuation of 571. Topics include an introduction to the theory of point estimation; consistency, efficiency, and sufficiency, and the method of maximum likelihood; the classical tests of hypotheses and their power; the theory of confidence intervals; the basic concepts of statistical decision theory; the fundamentals of sequential analysis.

### 574. ADVANCED PROBABILITY

Spring term. Credit four hours. Prerequisite: 571. M W F 11:15.

A continuation of Math 571. Selected topics from Volumes 1 and 2 of Feller, *An Introduction to Probability Theory*. Modern limit theorems, discrete and selected continuous parameter Markov chains, related topics in semigroups and resolvents, ergodic and renewal theorems with applications.

### 671-672. SEMINAR IN STATISTICS

Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor. M 4-6.

673. ANALYSIS OF VARIANCE

Fall term. Credit four hours. Prerequisites: 432 and 572. Hours to be arranged.

The classical univariate and multivariate normal procedures. Invariance, minimax and admissibility results. Ranking problems. Other models. Non-parametric methods.

674. DESIGN OF EXPERIMENTS

Spring term. Credit four hours. Prerequisite: 673. Hours to be arranged.

Algebraic and geometric construction of the classical balanced block designs. Optimum design theory. Sequential designs.

677-678. STOCHASTIC PROCESSES

Throughout the year. Credit four hours a term. Prerequisites: 511 or 522, 571 or consent of the instructor. First term prerequisite to second. Hours to be arranged.

Definition and basic properties of stochastic processes, martingales, sample path properties of stochastic processes, invariance principles. More detailed investigations of Markov processes and Markov chains, diffusion processes.

[575. INFORMATION THEORY]

Fall term. Credit four hours. Prerequisite: 411; or, with consent of the instructor of 416 or 421.

[675. STATISTICAL ESTIMATION]

Fall term. Credit four hours. Prerequisite: 572, 511 and some acquaintance with groups as in 432.

[676. DECISION FUNCTIONS]

Spring term. Credit four hours. Prerequisite: 675.

[679 (Also Economics 685). SEMINAR IN MATHEMATICAL ECONOMICS]

Spring term. Credit four hours. Prerequisite: consent of the instructor.

MATHEMATICAL LOGIC

581. LOGIC

Fall term. Credit four hours. Prerequisite: 432 or consent of the instructor. M W F 11:15.

Basic topics in mathematical logic including: propositional and predicate calculus, formal number theory and recursive functions, completeness and incompleteness theorems.

681-682. SEMINAR IN LOGIC

Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor. Hours to be arranged.

683. MODEL THEORY

Fall term. Credit four hours. Prerequisite: 581 or consent of the instructor. Hours to be arranged.

Construction and properties of models of axiomatic theories. Reduced products. Cardinality theorems. Preservation theorems. Nonelementary languages.

**684. RECURSION THEORY**

Spring term. Credit four hours. Prerequisite: 581 or consent of the instructor.  
M W F 11:15.

Theory of effectively computable functions. Classification of recursively enumerable sets. Degrees of recursive unsolvability. Applications to logic. Hierarchies. Recursive functions of ordinals and higher type objects. Generalized recursion theory.

**[685. METAMATHEMATICS]**

Spring term. Credit four hours. Prerequisite: 581 or consent of the instructor.

**[687. SET THEORY]**

Spring term. Credit four hours. Prerequisite: 581 or consent of the instructor.

**690. SUPERVISED READING AND RESEARCH**

## MECHANICAL ENGINEERING

Faculty: John F. Booker, Arthur H. Burr, Bart J. Conta, Terrill A. Cool, David Dropkin, George B. DuBois, Howard N. Fairchild, Benjamin Gebhart, Roger L. Geer, Sidney Leibovich, Howard N. McManus, Jr., Franklin K. Moore, Richard M. Phelan, Dennis G. Shepherd, Kenneth E. Torrance, Robert L. Wehe.

Field Representative: David Dropkin, 214 Upson Hall.

**MAJOR SUBJECTS**

Machine Design  
Thermal Power  
Thermal Processes

**MINOR SUBJECTS**

Machine Design  
Materials Processing  
Thermal Power  
Thermal Processes

The Graduate Field of Mechanical Engineering is composed of two departments: the Department of Machine Design and the Department of Thermal Engineering. The Machine Design Department is in charge of the teaching of machine design and materials processing subjects; the Thermal Engineering Department is in charge of the teaching of thermal power and thermal processes subjects.

Considerable latitude is allowed in the selection of the minor subjects. It is generally expected, however, that a major in thermal engineering be combined with a minor from some other department. Appropriate minor subjects, such as mathematics, nuclear engineering, electrical engineering, aerospace engineering, mechanics, etc., may be taken in other divisions of the University.

**ADMISSION REQUIREMENTS.** As a prerequisite for graduate study leading to the degree of M.S. or Ph.D. in the Field of Mechanical Engineering, the candidate should hold a Bachelor's degree and should have the equivalent of the fundamental work required in an accredited undergraduate curriculum in the area of his major work. Those lacking some of the necessary subject matter may be required to take one or more undergraduate courses or do assigned work to make up the deficiency.

**LANGUAGE REQUIREMENTS.** There is no foreign language requirement for the M.S. degree. For the Ph.D. degree a candidate must demonstrate reading ability in one language in addition to his native language. The required

language shall be chosen from French, German, Russian, or others to be approved by petition to the Field.

**EXAMINATIONS.** A final comprehensive examination is required for the M.S. degree. For the Ph.D. degree the student must take: (a) a qualifying examination (this may be combined with the examination for the M.S.); (b) the Admission to Candidacy Examination, a general examination of subject matter taken approximately at the time he completes his course work; and (c) a final examination which is primarily concerned with the doctoral dissertation.

**MACHINE DESIGN.** Unique instruction is offered in design and related subjects, including materials processing. The thesis and courses may be concentrated in one of the following areas or may overlap them: (1) design and development of a new machine, component, or system; (2) analysis of an existing machine, component, or system; (3) experimental investigation to determine design data and machine or tool performance.

The department has its own laboratories for stress, vibration, and endurance testing of machine parts, and for the study of controls. It is particularly well equipped for studies of lubrication phenomena in journal bearings, and for studies requiring use of analog computers. The materials processing laboratory includes many special production machines and gaging devices, and instrumentation for tool forces and temperatures.

Interests of the design staff are necessarily broad, and they overlap in a number of cases. However, based on current activities, they may be grouped as follows:

Hydrodynamic lubrication: John F. Booker, Robert L. Wehe.

Manufacturing engineering: George B. DuBois, Roger L. Geer.

Product design: George B. DuBois, Robert L. Wehe.

Stress and force analysis of mechanical components: Arthur H. Burr, Richard M. Phelan.

Vibration and controls: John F. Booker, Arthur H. Burr, Richard M. Phelan, Robert L. Wehe.

Students who major or minor in machine design usually take their other work in engineering mechanics, materials, materials processing, control systems and servo-mechanisms, mathematics, thermal engineering, agricultural engineering, or industrial engineering. Those minoring in materials processing may take supplementary studies in the Department of Materials Science and Engineering.

**THERMAL ENGINEERING.** There are excellent opportunities for both analytical and experimental studies at the graduate level in thermal engineering. The approved major and minor subjects are in two areas of special interest to the staff.

Under the subject, thermal processes, studies may be carried out in the areas of (1) fluid dynamics, including high-temperature and nonequilibrium effects, viscosity, radiative transfer, and plasma processes: Terrill A. Cool, Sidney Leibovich, Franklin K. Moore. (2) Heat transfer, including stability of convective flows, two-phase flows, boiling heat transfer, ablative heat transfer: David Dropkin, Benjamin Gebhart, Howard N. McManus, Jr., Kenneth E. Torrance. (3) Thermodynamics, including aspects of classical, statistical, and irreversible thermodynamics of concern in present-day technology: Bart J. Conta, Terrill A. Cool.

Under the heading thermal power, studies may be made of direct energy conversion, propulsion and nuclear power problems, use of solar energy,

turbomachinery, combustion engines, air conditioning and refrigeration, and heat pumps: Bart J. Conta, David Dropkin, Howard N. Fairchild, Dennis G. Shepherd.

In the laboratories of the School of Mechanical Engineering, instrumentation and equipment are available for the study of thermal processes and performance of engineering components and systems. In addition to the customary instruments, such as spectrometers, oscillographs, potentiometers, hot-wire anemometer, etc., the laboratory possesses a large Mach-Zehnder Interferometer of very high precision, a plasma arc generator capable of producing plasmas with high enthalpies and temperatures up to 25,000°F, and a solar collector apparatus suitable for thermal radiation studies. Several fans and compressors are available for a range of air flow, together with a gas-fired steam generating unit.

By a choice of his minor subject or subjects, the thermal engineering major may study at an advanced level in basic sciences, such as mathematics, physics, and chemistry, or in related engineering areas, such as aerospace engineering, chemical engineering, electrical engineering, applied physics, materials science, and theoretical and applied mechanics. The graduate student will ordinarily find it desirable to enroll in a number of the elective courses offered in the Department of Thermal Engineering, and he will be expected to participate in department seminars attended by students, staff, and visitors.

## Fellowships and Scholarships

In addition to the fellowships and scholarships that are available to all students in open competition, the following are restricted to M.S. and Ph.D. candidates majoring in the Field of Mechanical Engineering: Esso Education Foundation Fellowship, John McMullen Graduate Fellowship, Procter and Gamble Fellowship, Edgar J. Meyer Scholarship, Sibley Scholarship. (See pages 14-16.)

## Professional Degree

The degree of Master of Engineering (Mechanical) is available as a curricular type of professional degree, the general requirements for which are stated in the *Announcement of the College of Engineering*. Of the thirty credit hours required, the mechanical engineering program allows nine elective hours, together with considerable latitude in the choice of a laboratory course and the design project. In this way, an option is possible in a particular area, e.g., machine dynamics and control, mechanical analysis and development, vehicles and propulsion, propulsion engines, thermal environment, thermal power, thermal processes, manufacturing engineering, material removal, etc.

The professional degree, M.Eng.(Mech.), may be earned in a minimum of two terms of full-time study by the successful completion of the course requirements.

## Courses

### 3055. ADVANCED MECHANICAL ENGINEERING DESIGN

Spring term. Credit three hours. One lecture, two design periods. Prerequisite: 3054, Design of Mechanical Engineering Systems, or equivalent. Intended for graduate students. Staff and guest lecturers.

Design of mechanical engineering systems, components, and equipment in the widest sense, requiring the integration of engineering disciplines at an advanced level.

### 3090. MECHANICAL ENGINEERING DESIGN PROJECT

Spring term. Credit three hours. Intended for students in the M.Eng.(Mech) program. Staff.

Design of an engineering system or a device of advanced nature. Projects to be carried out by individual students or by small groups with individual assignments culminating in an engineering report by each student.

### 3116. INTRODUCTION TO INDUSTRIAL DESIGN

Fall term. Credit three hours. Two laboratories. Prerequisite: permission of the instructor.

Readings; abstract and applied design problems which investigate and apply the interrelationships existing between form, function, and materials.

### 3361. ADVANCED MECHANICAL ANALYSIS

Fall term. Credit three hours. Three recitations. Prerequisite: 3322 or 3331.

Theory of film-lubricated bearings; advanced analysis of special friction devices; theories of failure and design equations; prestressing; impact; thermal stresses and creep; selected topics from advanced strength of materials such as built-up cylinders, rotors, plates, shells, beams on elastic foundations, etc.

### 3362. MECHANICAL DESIGN OF TURBOMACHINERY

Spring term. Credit three hours. Three recitations. Prerequisites: 3324 and 3361.

Mechanical design of major components of high speed compressors and turbines for structural adequacy and vibration-free operation. Selected topics from among the following: design of rotor components, disks, vanes, blades, shafts, and connections. Design of bearings, seals, gaskets, expansion members. Investigation of natural frequencies and critical speeds. Selection of materials. Attention is called to a companion course, 3663.

### 3364. DESIGN FOR MANUFACTURE

Fall term. Credit three hours. Three recitations, one design or laboratory period. Prerequisites: 3322 or 3331, and 3431 or equivalent, or permission of the instructor. Messrs. DuBois and Geer.

Principles and methods of design to improve the producibility of machines and products. Design techniques to simplify and improve the processing operations, to reduce cost, and to increase accuracy and reliability. Designs and operation sequences for small-lot and large-lot manufacture to exploit the capabilities inherent in machine tools, jigs and fixtures, and other production equipment. Applications of the foregoing by design exercises.

### 3366. ADVANCED KINEMATICS

Fall term. Credit three hours. Two recitations, one computation period. Prerequisite: 3321.

Advanced analytical and graphical determination of velocities and accelerations in mechanisms. Special geometrical concepts on the kinematics of mechanisms. Synthesis of linkages by graphical and analytical methods. Design of linkages to give prescribed paths, positions, velocities, and accelerations.

### 3368. MECHANICAL VIBRATIONS

Spring term. Credit three hours. Two recitations, one laboratory. Prerequisite: 3324 or equivalent.

Further development of vibration phenomena in single and multi-degree of freedom linear and nonlinear systems, with emphasis on engineering problems involving analysis and design. Also gyroscopic effects, branched systems, random vibrations, impact and transient phenomena, isolation of shock and vibration, and noise and its reduction. Impedance, matrix, and numerical methods. Analog and digital computer solutions and laboratory studies.

### 3372. EXPERIMENTAL METHODS IN MACHINE DESIGN

Fall term. Credit three hours. One recitation, two laboratories. Prerequisite: 3322 or 3331. Mr. Phelan.

Investigation and evaluation of methods used to obtain design and performance data. Techniques of photoelasticity, strain measurement, photography, vibration and sound measurements, and development techniques are studied as applied to machine design problems.

### 3374. CONCEPTUAL DESIGN

Fall term. Credit three hours. Three recitations. Prerequisite: 3322 or equivalent. Mr. DuBois.

Conception and initial design of products and machines. Methods to stimulate mechanical ingenuity and improve appearance. Principles of synthesis and creativity employing association, inversion, and other techniques. Sketching, class discussion, and comparative evaluation of solutions.

### 3375. AUTOMATIC MACHINERY

Spring term. Credit three hours. Two recitations, one field trip. Prerequisite: 3321. Mr. Wehe.

A study of automatic and semiautomatic machinery such as dairy, canning, wire-forming, textile, machine-tool, computing, and printing equipment.

### 3377. AUTOMOTIVE ENGINEERING

Spring term. Credit three hours. Three recitations. Prerequisite: 3322. Mr. DuBois.

Analysis of various designs for the parts of an automotive vehicle, other than the engine, in relation to its performance; stability, weight distribution, traction, steering, driving, braking, riding comfort, power required and available, transmission types, acceleration, and climbing ability. Recommended together with Course 3670 for a study of automotive engineering.

### 3378. AUTOMATIC CONTROL SYSTEMS

Spring term. Credit three hours. Two recitations, one laboratory. Prerequisite: 3324 or equivalent. Mr. Booker.

Further development of feedback control theory, including stability criteria, frequency response, and transfer functions, with emphasis on engineering problems involving the analysis of existing control systems and the design of systems to perform specified tasks. Also, nonlinear systems, describing functions, sampled-data systems, and compensation techniques. Analog computer simulation and laboratory studies of hydraulic, pneumatic, and electromechanical components and systems.

### 3380. DESIGN OF COMPLEX SYSTEMS

Either term. Credit three hours. Two meetings of two hours per week to be arranged. Intended for graduate students in engineering. Permission of instructor required for registration. Mr. Wehe.

A seminar course relying heavily on student participation in discussing frontier problems such as systems for space and underwater exploitation, salt



water conversion, and transportation. Determination of specifications for these systems to meet given needs. Critical discussion of possible solutions based on technical as well as economic and social considerations. Reports will be required containing recommendations and reasoning leading to these considerations.

### 3382. HYDRODYNAMIC LUBRICATION

Credit three hours. Three recitations. Mr. Booker.

Design to acquaint those having a general knowledge of solid and fluid mechanics with the special problems and literature currently of interest in various fields of hydrodynamic lubrication. General topics include equations of viscous flow in thin films, self-acting and externally pressurized bearings with liquid and gas lubricant films, bearing system dynamics, digital and analog computer solutions. Also selected special topics in elastohydrodynamic, thermohydrodynamic, and magnetohydrodynamic lubrication.

### 3451. MATERIAL REMOVAL SYSTEMS

Fall term. Credit three hours. One lecture, two laboratories. Prerequisites: 3431 and 6316. Mr. Geer.

Advanced study of mechanics of chip formation. Forces and power dynamometry. Orthogonal and three dimensional relationships. Cutter geometry and chip control. Nonchip techniques using chemical, electrical, ultrasonic, and other media; surface characteristics; and postprocess treatments.

### 3461. QUALITY ASSURANCE SYSTEMS

Either term. Credit three hours. Two lectures, one laboratory. Prerequisites: 3431 and 9170. Mr. Geer.

Theory and computational techniques for control by attributes or variables. Machine tool capability studies, instrumentation systems. Standards codes and applications. Equipment performance characteristics. Fixed and comparative gaging systems; non-contact, reflective, and radiation principles. Surface texture phenomena. True-position tolerancing and charting.

### 3475. NUMERICAL CONTROL OF PROCESSES

Spring term. Credit three hours. Two lectures, one laboratory-computation. Prerequisite: 3431. Mr. Geer.

A thorough study of concepts, systems, and component designs for flexible-programmed processing. Machine tools as related to numerical control. Machine command-response factors, stick-slip, resonance, shaft windup, mass-inertia, and other effects. Positioning control systems and coding. Manual and computer programming. Simulation studies.

### 3651. ADVANCED THERMAL SCIENCE

Fall term. Credit three hours. Three recitations. Prerequisites: 3622, 3623, and 3625, or equivalent. Intended for graduate students in the M.Eng.(Mech.) program. Staff.

Advanced level study of topics from thermodynamics, fluid mechanics, and heat transfer. Selection of subjects from irreversible thermodynamics, statistical mechanics, real gas behavior, chemical thermodynamics, unsteady flow phenomena, gas dynamics, shock tube analysis, turbulent flow of jets and wakes, compressible boundary layer, numerical methods, and variable transport properties.

### 3652. COMBUSTION THEORY

Spring term. Credit three hours. Three lectures. Prerequisite: 3625. Mr. McManus.

Application of the basic equations of fluid flow and heat and mass transfer to homogeneous and diffusion flames. Ignition, quenching, rate processes, and dissociation effects will be examined. Consideration will be given to flame stabilization and practical systems.

### 3653. REFRIGERATION

Fall term. Credit three hours. Three recitations. Prerequisite: 3625, or 3625 concurrently. Mr. Fairchild.

Introduction to refrigeration with emphasis on application of thermodynamics, fluid dynamics, and heat transfer. Cycle and component performance. Applications in air conditioning and cold storage. Overall performance under varied operating conditions. Cryogenic refrigeration; gas liquefaction, purification, storage, and special heat transfer problems. Thermoelectric cooling.

### 3654. AIR CONDITIONING

Spring term. Credit three hours. Three recitations. Prerequisite: 3625 or 3625 concurrently. Mr. Fairchild.

Introduction to air conditioning with emphasis on application of thermodynamics, fluid dynamics, mass transfer, and heat transfer. Psychrometrics, air conditioning processes and cycles. Heat transmission in buildings; solar effects; lumped thermal circuit methods. Heat pumps. Air distribution. Component and system performance.

### 3661. EQUILIBRIUM THERMODYNAMICS

Fall term. Credit three hours. Three lectures. Intended for graduate students but open to qualified undergraduates. Prerequisites: 3621 and 3622 or equivalent. Mr. Conta.

A general treatment of classical or axiomatic thermodynamics with emphasis upon the mathematical developments and philosophical interpretations. Concepts and laws of thermodynamics and equivalence proofs. Homogeneous and pure substances, heterogeneous systems, and chemical thermodynamics. Equilibrium, irreversibility, and availability. The statistics of ensembles, classical and quantum statistics, and an introduction to information theory. The connections between the statistical and classical viewpoints.

### 3663. TURBOMACHINERY

Fall term. Credit three hours. Three recitations. Prerequisites: 3622 and 3623 or permission of the instructor. Mr. Shepherd.

Aerothermodynamic design of turbomachines in general, followed by consideration of specific types; fans, compressors, and pumps; steam, gas, and hydraulic turbines. Energy transfer between a fluid and a rotor; flow in channels and over blades. Compressible flow, three-dimensional effects, surging and cavitation. Outline design of a high-performance compressor-turbine unit. Attention is drawn to 3362 as a companion course for mechanical design.

### 3665. TRANSPORT PROCESSES

Fall term. Credit three hours. Three recitations. Prerequisites: basic thermodynamics and fluid mechanics. Mr. Gebhart.

Description of basic microscopic modes of thermal and mass diffusion. Molecular transport mechanics in gases. Formulation of the transport equations and their application to engineering problems. Conduction and mass diffusion in solids, boundary value problems. Thermal radiation between opaque surfaces in vacuum and as a diffusion process in nonopaque media. Mass and energy diffusion by molecular and by eddy processes in convection. Analytical methods in convection investigated, limits shown, and the role of correlations discussed. Analogous phenomena. Combined mode heat transfer.

**3667. TECHNIQUES OF THERMAL MEASUREMENT**

Spring term. Credit three hours. Two lectures, one laboratory. Prerequisite: 3625. Mr. Dropkin.

Theory, construction, calibration, and application of liquid-in-glass thermometers, solid expansion thermometers, pressure-spring thermometers, resistance thermometers, thermoelectric thermometers, optical pyrometers, radiation pyrometers, enthalpy probes, heat flux probes.

**3670. ADVANCED COMBUSTION ENGINES**

Spring term. Credit three hours. Three recitations. Prerequisite: 3669, or equivalent. Mr. Fairchild.

Advanced study of topics in field of reciprocating engines, both spark-ignition and diesel. Methods of thermodynamic analysis and performance prediction for free-piston power plants and supercharged engines. Relation of engine performance characteristics and performance characteristics of automotive vehicles. Recommended together with 3377 for study in automotive engineering.

**3671. AEROSPACE PROPULSION SYSTEMS**

Spring term. Credit three hours. Three recitations. Prerequisites: 3622 and 3623, or permission of the instructor. Mr. Shepherd.

Intended for graduate students and qualified undergraduates. Application of thermodynamics and fluid mechanics to the design and performance of thermal-jet and rocket engines in the atmosphere and in space. Mission analysis in space as it affects the propulsion system. Consideration of auxiliary power supply; study of advanced methods of space propulsion.

**3672. ENERGY CONVERSION**

Spring term. Credit three hours. Three lectures. Prerequisite: 3622 or equivalent. Mr. Conta.

Primarily an analysis of energy conversion devices from a classification into heat engines, chemical engines, and expansion engines. An analysis of each class from the point of view of efficiency and other criteria of performance. A more detailed study of some conventional and some direct energy conversion devices including thermoelectric, thermionic, and photovoltaic converters; and fuel cells. Energy sources and energy storage, applications to terrestrial and space power systems.

**3673. ADVANCED FLOW MEASUREMENT**

Fall term. Credit three hours. Two lectures, one laboratory. Mr. McManus.

Theory and operation of instruments used in fluid flow investigations; hot wire anemometers; density-sensitive optical systems, transient temperature and pressure measurements; measurements in reacting systems; error analysis and treatment of data.

**3674. STATISTICAL THERMODYNAMICS**

Spring term. Credit three hours. Three recitations. Intended for graduate students but open to qualified undergraduates. Prerequisites: 3622, 3623 or equivalent. Mr. Cool.

The statistical mechanical basis of the first and second laws of thermodynamics. The interrelationships between classical thermodynamics and the fields of classical, quantum, and statistical mechanics. The statistical mechanics of ideal and real gases, black body radiation, diatomic molecular systems, and fluctuations. Thermal considerations of molecular laser systems. Equilibrium in multicomponent systems.

**3675. THEORETICAL FLUID MECHANICS I**

Fall term. Credit three hours. Three recitations. Prerequisite: concurrent enrollment in 1180 or equivalent. Mr. Leibovich.

Navier-Stokes equation and exact solutions. Vorticity theorems. Irrotational incompressible flow in two and three dimensions. Wing theory, slender body theory. Rotational flow including shear-induced secondary flows, effects of strong rotation or stratification, Ekman layers. Compressible flow in one dimension, wave equation, Riemann invariants. Shock waves.

**3676. THEORETICAL FLUID MECHANICS II**

Spring term. Credit three hours. Three recitations. A continuation of 3675. Mr. Moore.

Effects of viscosity including exact solutions, boundary-layer theory and calculation methods; similarity solutions; displacement effects; wake flows; dissipation of sound waves and weak-shock structure. Stability of laminar flows and elements of turbulence theory. Supersonic and hypersonic flow fields. Two-phase flow.

**3680. ADVANCED CONVECTION HEAT TRANSFER**

Spring term. Credit three hours. Three recitations. Prerequisite: 3665 or consent of the instructor. Mr. Gebhart.

Processes of transport of thermal energy, momentum, and mass in fluids are considered in detail. Theories of transfer processes and analytic solutions. Analytical and experimental results compared. Transport equations for a fluid, delineation of kinds of processes, differential similarity, natural convection, forced convection at low and high velocities. Boundary layer solutions, similarity theories, and effects of turbulence. Transport in rarefied gases.

**3681. NONEQUILIBRIUM FLOW AND RADIATIVE TRANSFER**

Fall term. Credit three hours. Three recitations. Prerequisites: 3674 and 3676 or equivalent. Mr. Moore.

The influence of physical and chemical nonequilibrium, including surface effects, on gasdynamics, fluid mechanics and heat transfer. Flows including sound and shock waves, viscous waves and boundary layers, hypersonic shock layers and wakes, and channel and nozzle flows. Nonequilibrium processes including vibrational and chemical relaxation and, especially, radiative transfer of heat.

**3682. SEMINAR IN HEAT TRANSFER**

Spring term. Credit three hours. Two meetings of two hours per week to be arranged. Prerequisite: permission of the instructor. Mr. Gebhart.

Discussion of fields of active inquiry and current interest in heat transfer. Considerations of major recent work and several summaries of associated contributions.

## MEDICAL SCIENCES

### Graduate School of Medical Sciences

See page 51 of this *Announcement*.

Requests for information regarding the Fields in the Medical Sciences should be addressed to Professor Julian R. Rachele, Assistant Dean, Graduate School of Medical Sciences, Cornell University, Medical College, 1300 York Avenue, New York, N.Y. 10021.

## Biomathematics

A new program of applied mathematics in biology is offered by the Biomathematics Division to students whose primary interests are mathematical or theoretical, but who wish to concentrate on biological applications. Programs leading to the Ph.D. degree are flexible to suit the particular area of biological application of the individual student, and appropriate courses of study in the relevant aspects of biology, chemistry, physics, and medicine are planned accordingly.

## Biophysics

Graduate work toward the Ph.D. degree in Biophysics and the M.S. in Radiation Physics is offered, as well as opportunities for postdoctoral research in Biophysics. Active research programs are being conducted in fundamental radiation biophysics, including cellular radiobiology, and in the biophysics of membrane transport.

## Biostatistics

The graduate biostatistics program offered by the Biomathematics Division applies the quantitative methods of the theory of probability and statistics to biological or medical problems. The use of modern computers is an integral part of the program which leads to the Ph.D. degree.

## NUCLEAR SCIENCE AND ENGINEERING

Faculty: K. Bingham Cady, David D. Clark, Trevor R. Cuykendall, David Dropkin, Charles D. Gates, Simpson Linke, Raphael M. Littauer, Ross McPherson, George H. Morrison, Mark Nelkin, Robert L. Von Berg.

Visiting Professor: Ivan Kuščer.

Field Representative: Ross McPherson, Nuclear Reactor Laboratory.

### MAJOR SUBJECTS

Nuclear Science  
Nuclear Engineering

### MINOR SUBJECT

Nuclear Engineering

**ADMISSION REQUIREMENTS.** A Bachelor's degree in science or engineering, including one year of advanced calculus and a one-year course in atomic and nuclear physics is required. Students with less preparation may be admitted if their undergraduate performance is outstanding, but they should expect to take longer to complete the degree requirements. Applicants who are United States citizens are normally expected to apply for the Atomic Energy Commission Special Fellowships in Nuclear Science and Engineering. Applications may be obtained from the Fellowship Office, Oak Ridge Institute for Nuclear Studies, Oak Ridge, Tennessee 37831.

**LANGUAGE REQUIREMENTS.** The language requirement for the Ph.D. degree is a reading knowledge of one language other than English. There is no language requirement for the M.S. degree.

**EXAMINATION REQUIREMENTS.** Before the beginning of his second term of graduate study the student is expected to form his Ph.D. Special Committee. This committee will normally be composed of (1) a chairman, who will be the student's major advisor, (2) a faculty member representing a minor subject outside the Field, and (3) a second member of the Field faculty appointed by the Field Representative. Additional members representing other minor subjects are permitted. As soon as the committee is formed it will administer an informal oral examination designed primarily to guide the course of the student's future study and research. Before the end of the fifth term of graduate study, the committee will administer the Admission to Candidacy Examination. This examination is both written and oral, and covers the core of the graduate course program. Advanced courses in special topics will be taken by most students after this examination, but the passing of this examination signifies a shift in primary emphasis from course work to research.

## Research and Study Opportunities

Research in nuclear physics and reactor physics requires a knowledge of a number of scientific and engineering disciplines. The organization of the graduate program encourages this kind of interdisciplinary study.

Basic research in low energy nuclear physics and reactor physics at Cornell is centered at the facilities of the Nuclear Reactor Laboratory. In addition to students in Nuclear Science and Engineering, these facilities are used by students from other fields who are performing related research. The major facilities and typical uses are: 1) a TRIGA reactor with a steady state power of 100 kilowatts and a pulsing capability of up to 250 megawatts. The reactor is a source of neutrons and gamma rays for activation analysis, solid and liquid state studies, and nuclear physics. In addition to standard pneumatic and mechanical transfer systems, the reactor is equipped with a 40-millisecond rapid transfer system in one of the six-beam ports which allows study and use of radio-nuclides having a relatively short half-life. 2) Cornell Critical Facility, a "zero power reactor" of very versatile design for basic studies in reactor physics and dynamics. Equipment ancillary to the reactor includes a pulsed 14 MeV neutron generator used for studies of reactor transients. 3) Sub-critical assemblies for reactor physics investigations. 4) Gamma Cell, a shielded cell with a nominal 10,000 Curie  $\text{Co}^{60}$  gamma ray source for radiation chemistry and radiation damage studies. The cell is complete with viewing window and remote manipulators which allow experimental versatility within the cell. 5) 3 MeV Dynamitron, a positive ion accelerator of high current capability for nuclear structure studies and high intensity radiation damage studies. A lithium target for controlled energy neutron production has been developed which is capable of power dissipation approaching 10,000 watts/cm<sup>2</sup>.

Faculty research interests are:

K. Bingham Cady: nuclear engineering, reactor physics  
 David D. Clark: nuclear and reactor physics, radiation detection  
 Trevor R. Cuykendall: nuclear engineering  
 David Dropkin: heat transfer, thermal processes  
 Charles D. Gates: nuclear environmental engineering  
 Ivan Kuščer: neutral particle transport theory  
 Simpson Linke: energy conversion  
 Raphael M. Littauer: nuclear instrumentation, pulse electronics  
 Ross McPherson: nuclear physics and instrumentation

George H. Morrison: nuclear chemistry

Mark Nelkin: neutron scattering, transport and kinetic theory

Robert L. Von Berg: radiation chemistry, chemical engineering

Research groups in nuclear science are currently pursuing studies of nuclear structure, analytical nuclear chemistry, and theoretical studies related to neutron transport. Examples of current experimental research topics include: the study of short-lived isomers produced by the intense neutron flux of the pulsed TRIGA reactor; the structure of light nuclides studied by using particle reactions at the 3 MeV accelerator; and activation analysis of meteoritic and geological samples using the TRIGA reactor and high resolution gamma ray spectrometry apparatus. Recent theoretical studies include: slow neutron inelastic scattering from liquids and kinetic theory of time-dependent correlation in fluids.

Current examples in nuclear engineering include: basic reactor dynamics; pulsed neutron experiments in multiplying media; theory and measurement of neutron importance; space-dependent reactor kinetics and noise analysis; stochastic theory of neutron transport; thermionic energy conversion; and radiation chemistry.

The detailed program of studies is not prescribed as a curriculum, but is planned by each individual student and the faculty members of his Special Committee. There is, however, a common core of subject matter for study in this Field. This includes the material covered in 8309, 8312, and 8351 as listed in the following pages, a knowledge of applied mathematics through Mathematics 416 or 423, a knowledge of theoretical physics including the graduate quantum mechanics course, Physics 572, and at least one two-term graduate course sequence in some area of engineering. Students majoring in nuclear engineering will also take additional courses from the following list. Students majoring in nuclear science will normally take additional courses in physics at the graduate level.

## Professional Degree

The Master of Engineering (Nuclear) program is a two-term program intended for students who want a terminal degree and for students who want an interim degree before doctoral study in Nuclear Science and Engineering. The program develops the basic principles of nuclear reactors and shows a student how his field of undergraduate specialization may be applied to nuclear engineering problems. The recommended entrance requirements include:

1. A Bachelor's degree in engineering, applied science, or its equivalent.
2. Physics, including atomic and nuclear physics.
3. Mathematics, including advanced calculus.
4. Thermodynamics.

Students should make every effort to complete the entrance requirements before beginning the program; this may be done in some cases by informal study during the summer. For further information write to Nuclear Engineering Field Representative, Nuclear Reactor Laboratory.

## Financial Aid

In addition to the Cornell University awards, there are special fellowships for students in nuclear science and engineering that are awarded nationally

by the United States Atomic Energy Commission and by the National Science Foundation. Application materials for AEC support may be obtained from the Fellowship Office, Oak Ridge Associated Universities, Box 117, Oak Ridge, Tennessee 37830. Applications are usually due early in January.

Applications for NSF fellowships are normally due early in December and are made directly to NSF on forms obtainable from the National Science Foundation, Fellowship Office, National Research Council, 2101 Constitution Avenue, Washington, D.C. 20037.

All students currently pursuing studies for advanced degrees receive financial support. Any student making good progress toward an advanced degree may expect continuing support through an assistantship, fellowship, or a traineeship awarded by the AEC or NSF.

## Courses

### 8303. INTRODUCTION TO NUCLEAR SCIENCE AND ENGINEERING

Fall term. Credit three hours.

A lecture and seminar course providing an introduction to nuclear engineering and low-energy nuclear physics for qualified juniors and seniors and graduate students majoring in subjects other than nuclear science or nuclear engineering. The objective is to relate the experience of students in other fields to nuclear science and engineering. Topics include: systematics of nuclear structure; properties of nuclear radiations; nuclear fission and the neutron chain reaction; and the classification and uses of nuclear reactors. Messrs. Cady and McPherson.

### 8309. LOW-ENERGY NUCLEAR PHYSICS

Spring term. Credit four hours. Three lectures. Prerequisite: an introductory course in atomic and nuclear physics, including quantum mechanics. Mr. McPherson.

Low energy nuclear physics as an organized body of experimental facts. Properties of ground and excited states of nuclei; models of nuclear structure; low-energy nuclear reactions-scattering, absorption, fission, resonance effects, coherent scattering effects. At a level between *Introductory Nuclear Physics* by Halliday, and *Nuclear Physics* by Fermi.

### 8312. NUCLEAR REACTOR THEORY I

Fall term. Credit four hours. Three lectures. Prerequisites: one year of advanced calculus and an introductory course in atomic and nuclear physics.

The physical processes in neutron chain reactors are described. The theory of neutron diffusion and slowing down is developed and applied to these processes. Neutron transport theory is introduced. At the level of *Nuclear Reactor Theory* by LaMarsh.

### 8313. NUCLEAR REACTOR THEORY II

Spring term. Credit three hours. Three lectures. Continuation of 8312, primarily intended for students planning to do research in the fields of reactor physics and reactor engineering. Mr. Cady.

Delayed neutron kinetics, fission product poisoning, nonlinear kinetics, perturbation theory, theory and measurement of neutron importance, temperature coefficients, control rod theory, hydrogenous reactors, neutron transport, and heterogeneous reactor theory. At the level of *The Physical Theory of Neutron Chain Reactors* by Weinberg and Wigner.



**8314. NEUTRON TRANSPORT THEORY**

Spring term. Credit three hours. Prerequisite: 8312 or consent of the instructor. Mr. Kušcer.

The linear Boltzmann equation describing neutron migration in matter is intensively studied. Topics will vary, but may include Milne's problem, neutron thermalization, deep penetration of radiation, as well as a formal development of approximate methods of solution. At the level of *Neutron Transport Theory* by Davison.

**8333. NUCLEAR REACTOR ENGINEERING**

Fall term. Credit four hours. Three lectures. Prerequisite: consent of the instructor. Mr. Cady.

A selected set of topics representing the fundamentals of nuclear reactor engineering; energy conversion and power plant thermodynamics, fluid flow and heat transfer, thermal stresses, radiation protection and shielding, materials for nuclear reactors, economics of nuclear power and fuel cycles, instrumentation and control. At the level of *Nuclear Reactor Engineering* by Glasstone and Sesonske.

**8334. NUCLEAR ENGINEERING SEMINAR**

Spring term. Credit four hours. Prerequisite: 8333. Mr. Cady.

A conceptual design study of a nuclear reactor system. Emphasis on the interplay of requirements of safety and economics in the design of nuclear power systems.

**8337. MATERIALS SCIENCE FOR ENGINEERS (MATERIALS SCIENCE 6873)**

Fall term. Credit three hours. Three lectures.

Structure of crystals. Crystal lattice properties. Crystal defects (point, line, planar). Thermodynamics of solids. Diffusion and kinetics (emphasis on defect annealing, e.g., polygonization, recrystallization, grain growth, point defect recovery, etc.). Mechanical properties (role of crystal defects in plastic deformation, creep, fracture). Topics in radiation damage including defect productions, radiation damage annealing and effect of damage on physical properties.

**8351. NUCLEAR MEASUREMENTS LABORATORY**

Spring term. Credit four hours. Two afternoon periods of two and a half hours each. Prerequisite: some knowledge of nuclear physics. Mr. McPherson.

Laboratory experiments plus lectures on interaction of radiation with matter and on radiation detection, including electronic circuits. Some twenty different experiments are available in the areas of nuclear and reactor physics. Among these are experiments on emission and absorption of radiation; on radiation detectors and nuclear electronic circuits; on interactions of neutrons with matter (absorption, scattering, moderation, and diffusion); on activation analysis and radiochemistry; and on properties of a subcritical assembly. Many of the experiments use the TRIGA Reactor. The student is expected to perform eight to ten experiments, selected to meet his needs.

**8352. ADVANCED NUCLEAR AND REACTOR LABORATORY**

Either term. Credit three hours. Two afternoon periods of two and a half hours each. Prerequisites: 8309 and 8351 or 8312. Mr. McPherson.

Laboratory experiments plus informal lectures on experimental methods in nuclear physics and reactor physics. Some ten different experiments are available, among them one using the Zero Power Reactor critical facility.

## OPERATIONS RESEARCH

Faculty: Robert E. Bechhofer, Richard H. Bernhard, Louis J. Billera, Mark Brown, Richard W. Conway, Stella C. Dafermos, Hamilton Emmons, Henry P. Goode, Jack C. Kiefer, Kenneth O. Kortanek, Walter R. Lynn, William L. Maxwell, Howard L. Morgan, Narahari U. Prabhu, Sidney Saltzman, Byron W. Saunders, Andrew Schultz, Jr., Howard M. Taylor 3d, Lionel I. Weiss.

Field Representative: Lionel I. Weiss, 370 Upson Hall.

### MAJOR AND MINOR SUBJECTS

The Field of Operations Research offers doctoral programs in four major subjects: operations research, applied probability and statistics, systems analysis and design, and industrial engineering. Master of Science programs are offered in all the above subjects, as well as in information processing.

A general description of the five subjects is given below.

**OPERATIONS RESEARCH.** The problem areas and techniques of operations research are approached from a highly analytical viewpoint. Emphasis is placed on constructing appropriate mathematical models to represent various real-life operational systems, and on developing techniques for analyzing the performance of these models. In this way procedures with desirable properties for dealing with such systems are developed. Queuing, inventory, reliability, replacement, and scheduling theories are among the major techniques employed. Optimization techniques such as mathematical programming (linear, nonlinear, and probabilistic), combinatorics, and dynamic programming are also used extensively.

The operations research student pursues a course of study and research that emphasizes the use of the mathematical, probabilistic, statistical, and computational sciences in the development of the techniques of operations research. However, his ultimate goal may range from making a fundamental contribution to the techniques of operations research to applying operations research to problems in diverse professional areas.

**APPLIED PROBABILITY AND STATISTICS.** This subject of study and research is designed for students having primary interests in the techniques and the associated underlying theory of probability and statistics, particularly as they are applied to problems arising in science and engineering. The techniques emphasized are those associated with applied stochastic processes (for example, queuing theory, inventory theory, and time-series analysis) and statistics (including statistical decision theory; the statistical aspects of the design, analysis, and interpretation of experiments, and of ranking and selection theory; reliability theory; statistical quality control; sampling inspection; and acceptance sampling).

Because a doctoral dissertation must represent a fundamental contribution to theory and application, students who elect work in this area are expected to acquire considerable knowledge of the theory of probability and statistics. In addition, all students who major in applied probability and statistics are required to minor in mathematics.

**SYSTEMS ANALYSIS AND DESIGN.** Although the solution of systems problems requires knowledge of underlying theory, the inherent practical limitations of the problem must be understood. Analysis of a system alone is insufficient; alternative solutions must be generated before selecting the one which can best be integrated with other elements of the system. Modeling concepts are equally important, but only when they can produce workable

systems. Illustrations of the design of integrated systems can be found in industry, the environment, commerce, and government. Research activity may involve the developing of new methodology, or the synthesizing of new combinations from what is already known. Such activity can improve the understanding of systems or can lead to the development of new decision criteria for such systems.

**INDUSTRIAL ENGINEERING.** Studies of the analysis and design of the complex operational systems that occur in industry, particularly in manufacturing, are included in this subject. Plant design, cost analysis and control, and production planning represent some of the major topics. A student is expected to have considerable facility in the modern analytical techniques associated with rational decision making and with the establishment of valid design criteria. These techniques are drawn from among inventory theory, queuing theory, mathematical programming, quality control, and computer simulation.

Because the design and operation of modern engineering systems applies to areas other than manufacturing, the use of the word "industrial" should not be considered restrictive. Industrial engineers frequently are employed as systems specialists in commerce, banking, distribution, merchandising, and hospital management.

**INFORMATION PROCESSING.** Information processing deals with the analysis and design of systems which record, transmit, store, and process information. The application and integration of equipment is emphasized rather than the design of machines. Areas of interest include systems for information retrieval, manufacturing control, and traffic control. This subject also includes such underlying theoretical topics as information theory and computing language structure. The principal campus computing facility is an IBM 360/65, with on-line operation from many campus locations. A satellite 360/20 directly connected to the 360/65 is located in Upson Hall where the Department of Operations Research is housed. Teletypewriter terminals are also in use.

**APPROPRIATE MINOR SUBJECTS.** The following minor subjects have been chosen most frequently in recent years: computer science (Computer Science), econometrics and economic statistics (Economics), managerial economics (Business and Public Administration), mathematics (Mathematics), regional planning (City and Regional Planning), and water resources (Water Resources). Students who are interested in minoring in any of these subjects should refer to the respective Field programs listed elsewhere in this announcement.

**ADMISSION REQUIREMENTS.** As a prerequisite for graduate study leading to the degree of M.S. or Ph.D. with a major in the Field of Operations Research, the candidate must have been graduated from an institution of recognized standing with a Bachelor's degree in engineering, mathematics, economics, or the physical sciences. In addition, he must have a commendable undergraduate scholastic record and must supply other evidence of his interest in, and ability to pursue, advanced study and research in his major and minor subjects. It is strongly recommended that all applicants to the Field take the Graduate Record Examination and submit the results along with their application for graduate study. Fellowship and assistantship applicants must submit this examination.

**LANGUAGE REQUIREMENTS.** A student in a Ph.D. program must demonstrate reading ability in one foreign language. The required language shall

be chosen from French, German, Russian, or others to be approved by petition to the Field. There is no language requirement for the M.S. degree.

**PH.D. EXAMINATIONS.** In addition to the Admission to Candidacy Examination which will ordinarily be administered by the student's Special Committee during the third year of graduate study, and the Final Examination on the thesis, the student will be given a qualifying examination administered by the Field. This latter examination will normally be taken during the second term of graduate study. It shall serve to determine the ability of the candidate to pursue doctoral studies, and to assist the Special Committee in developing a program of study for the candidate.

## Research Interests of the Faculty

Robert E. Bechhofer: engineering statistics, design of experiments, ranking and selection procedures.

Richard H. Bernhard: capital investment planning, cost analysis and control.

Louis J. Billera: game theory, combinatorial analysis, graph theory.

Mark Brown: stochastic processes, time-series analysis.

Richard W. Conway: information processing systems, computer science.

Stella C. Dafermos: systems analysis, network theory.

Hamilton Emmons: operations research, inventory theory.

Henry P. Goode: manufacturing engineering, industrial statistics, sampling inspection.

Jack C. Kiefer: statistical decision theory, optimum experimental design, sequential analysis.

Kenneth O. Kortanek: mathematical programming, systems analysis.

Walter R. Lynn: environmental systems.

William L. Maxwell: information-processing systems, production control, systems simulation.

Howard L. Morgan: management information systems, information-processing.

Narahari U. Prabhu: stochastic processes, queuing theory, storage theory.

Sidney Saltzman: information-processing systems, operations research, econometrics.

Byron W. Saunders: facility design, materials handling, manufacturing design.

Andrew Schultz, Jr.: operations research, systems analysis.

Howard M. Taylor 3d: statistical control theory, time-series analysis, statistical prediction.

Lionel I. Weiss: statistical decision theory, sequential analysis, nonparametric statistics.

**RESEARCH OPPORTUNITIES.** During the academic year 1969-70 several members of the faculty will be engaged in sponsored research on contracts or grants which provide financial support and which offer opportunities for thesis research for advanced graduate students. The research areas include statistical multiple-decision ranking and selection procedures, stochastic models for hydrology, information-processing and operations control systems, sequential procedures and applied stochastic processes, extensions of semi-infinite programming duality, applications of statistical control theory, development of Cornell University programming languages, and traffic control in urban networks.

### DEPARTMENTAL FELLOWSHIPS

In addition to several University-wide and College of Engineering fellowships, the following fellowships are specifically designated for incoming candidates in the Field of Operations Research:

*John McMullen Graduate Fellowship.* \$2,000 plus tuition and fees.

*Procter and Gamble Fellowship.* \$2,000 plus tuition and fees. A \$700 allowance is available if the recipient is married.

*Sun Oil Fellowship.* \$2,475 plus tuition and fees if the recipient is single or married without children. A \$450 allowance is available if the recipient is married and has children.

*Dexter S. Kimball Fellowship of Aeronautical Laboratory.* \$2,500 or more plus tuition and fees.

## Master of Engineering (Industrial)

The Master of Engineering program is designed for those primarily interested in becoming proficient in the practice of modern industrial engineering and consists of coordinated course work that is concentrated on advanced analytical and design techniques. Special emphasis is placed on applications. In addition, candidates work on projects which require identification, analysis, and design of feasible solutions to some loosely structured engineering problems.

To be considered for this program an applicant must have a Bachelor's degree in an engineering field and a commendable undergraduate record. Should his undergraduate program provide adequate preparation (approximately equal to the required forty semester credit hours of the Cornell undergraduate Field Program in Industrial Engineering), requirements for this degree can usually be completed in one academic year.

Information and applications for this program may be obtained by writing to Professor Byron W. Saunders, Director of the School of Industrial Engineering and Operations Research, Upson Hall.

## Courses

### 9460. INTRODUCTION TO PROBABILITY THEORY WITH ENGINEERING APPLICATIONS

Fall term. Credit four hours. Three lecture-recitations, one computation period. Prerequisite: Mathematics 294 or equivalent.

Definition of probability and basic rules of probability theory. Random variables, probability distributions, and expected values. Special distributions important in engineering work and relations among them; elementary limit theorems. Introduction to stochastic processes and Markov chains, and their applications in the construction of mathematical models of operation, with emphasis on queuing and inventory models.

### 9470. INTRODUCTION TO STATISTICAL THEORY WITH ENGINEERING APPLICATIONS

Spring term. Credit four hours. Three lecture-recitations, one computation period. Prerequisite: 9460.

The application of statistical theory to problems associated with the analysis of data and inference drawn therefrom. Principles of statistical inference: estimating the value of the unknown parameters of probability distributions,

testing hypotheses concerning these parameters; elements of statistical decision theory. Introduction to correlation theory and curve fitting by least squares. Applications in regression, statistical control, and experimentation.

**9481. INTRODUCTION TO COMPUTER SCIENCE** (Same as Computer Science 401)

Fall term. Credit three hours. Two lectures, one recitation-computation.

Introduction to the field of Computer Science including principles and characteristics of information-processing equipment, programming languages, and applications. Topics are selected to illustrate a wide range of current and potential areas of application with emphasis being placed on the modern digital computer as a symbol-manipulating device rather than as an arithmetic calculator. Number systems, computer logic, and organization, and characteristics of current equipment are covered along with various aspects of programming. Introductory concepts and problems associated with using computers in information-processing systems, real-time control systems, simulated experimentation, and the design process are also considered.

**9501. ENGINEERING ADMINISTRATION**

Spring term. Credit three hours. Three lecture-recitation periods. Prerequisite: graduate standing.

Organization of the engineering function, planning and analysis of engineering activities. Project management and control. Problems of innovation and introducing technological change. Measurement and evaluation of engineering activities. Selected topics from current literature.

**9511. MANUFACTURING ENGINEERING**

Fall term. Credit three hours. One lecture, one recitation-computation period. Prerequisite: 9311.

The analysis and design of production facilities based on output requirements of the system. Attention will be directed toward the interaction of processing methods and requirements with handling methods and storage facilities. The effects of various levels of mechanization on operating costs and initial investment will be studied.

**9512. STATISTICAL METHODS IN QUALITY AND RELIABILITY CONTROL**

Spring term. Credit three hours. Three lectures. Prerequisite: 9470 or equivalent.

Control concepts; control chart methods for attributes and for variables; process capability analysis; attributes acceptance-sampling plans and procedures; double- and multiple-sampling inspection; elementary plans and procedures for variables; acceptance-rectification procedures; basic reliability concepts; exponential and normal distributions as models for reliability application; life and reliability analysis of components; analysis of series and parallel systems; stand-by and redundancy; elementary sampling-inspection procedures used for life and reliability.

**9513. SYSTEMS ENGINEERING**

Spring term. Credit three hours. Two recitations, one laboratory. Prerequisite: 9320 and 9370 or permission.

Methods of describing, analyzing, and manipulating complex, interrelated open systems. Graphical and mathematical analysis. Techniques of design of transportation, service, and information systems and appropriate evaluation methods.

**9521. PRODUCTION PLANNING AND CONTROL**

Spring term. Credit four hours. Three recitations, one computation period. Prerequisites: 9320 and 9321, or permission of the instructor.

Methods for the planning and control of large-scale operations with emphasis on manufacturing systems. Among the areas covered will be sales and production forecasting; manufacturing-planning; routing, scheduling, and loading; sequencing; dispatching; planning and control of inventories. Emphasis will be on mathematical and statistical methods for performing these functions; however, the empirical systems and procedures in common use will also be discussed and evaluated.

**9522. OPERATIONS RESEARCH I**

Fall term. Credit three hours. Three lecture-recitation periods. Prerequisite: permission of the instructor.

Model design, methodology of operations research, linear programming, transportation problem, assignment problem, dual theorem, parametric linear programming, integer programming, nonlinear programming, dynamic programming, introduction to inventory theory; comprehensive problems and case studies.

**9523. OPERATIONS RESEARCH II**

Spring term. Credit three hours. Three lecture-recitation periods. Prerequisite: 9460 or permission of the instructor.

Models for inventory and production control; replacement theory; queuing, including standard birth- and death-process model and nonstandard models, application of queuing theory; simulation; game theory; illustrative examples and problems.

**9524. PROBLEMS IN OPERATIONS RESEARCH**

Credit three hours. A two-hour meeting a week. Prerequisite: 9523 or equivalent.

An advanced seminar concentrating on problem definition, measures of effectiveness, applicability of various analytical methods to the solution of real problems.

**9525. FLOW AND SCHEDULING IN NETWORKS**

Spring term. Credit three hours. Three lecture-recitation periods.

Network analysis for continuous static flow; feasibility theorems, capacity determination, minimal cost operation. Sequencing models for deterministic discrete flow networks. Determination of capacity, routing and discipline for networks of queues.

**9526. MATHEMATICAL MODELS—DEVELOPMENT AND APPLICATION**

Fall term. Credit four hours. Three lecture-recitations, one computation period. Prerequisites: 9311 and 9320 or permission of the instructor.

Examination of both probabilistic and deterministic models used in industrial engineering work. Problems will be given in which the student will develop his own version of a proper model to describe the situation.

**9529. PROBLEMS AND TECHNIQUES IN OPTIMIZATION**

Spring term. Credit three hours. Three lecture-recitation periods. Prerequisites: 9360, 9370, and 9320.

The application of a variety of operations research techniques and analytical skills in actual concrete situations. Lectures on enumeration methods as found

in branch and bound techniques, discrete dynamic programming, column generation methods, linear programming, quadratic assignment techniques, combinatorial analysis and graph theoretic techniques, and networks including techniques for handling problems of uncertainty. Problems will be selected from such areas as multidimensional trim problems, networks and scheduling problems, maintenance problems, routing problems, selection problems, fixed charge problems, location problems, and special problems in optimal design of production and distribution systems within the context of a vertically integrated firm.

### 9530. MATHEMATICAL PROGRAMMING I

Spring term. Credit three hours. Three lecture-recitation periods. Prerequisites: Math 331 and Math 441 or 9320 or permission of the instructor.

The geometry and duality of linear programming. Complete regularization and the resolution of degeneracy. Adjacent extreme-point methods such as the simplex, dual and multipage in linear and nonlinear problems. Models of transportation and network type, and zero-sum and two-person games. Mixing routines and decomposition. Introduction to integer programming. Convex programming and Kuhn-Tucker theory.

### 9531. MATHEMATICAL PROGRAMMING II

Fall term. Credit three hours. Three lecture-recitation periods. Prerequisite: 9530.

Complementary pivot theory. Semi-infinite programming and duality in convex programming. Computational algorithms. Integer programming. Chance-constrained programming and piecewise-linear decision rules. Combinatorial analysis and extremal methods.

### 9533. GRAPH THEORY AND COMBINATORIAL ANALYSIS

Spring term. Credit three hours. Three lecture-recitation periods. Prerequisites: permission of the instructor.

Finite, infinite, directed, undirected, combinatorial, and topological graphs. Connectedness, planarity, coloring and matching problems, matrix methods, network problems. Applications to electrical networks, economics, and sociometry. Incidence systems such as finite geometries and block designs. Matrices of zeros and ones, perfect difference sets, Latin squares. Combinatorial extremum problems.

### 9535. GAME THEORY

Spring term. Credit three hours. Three lecture-recitation periods. Prerequisite: permission of the instructor.

Two-person zero-sum games; the minimax theorem, relationship to linear programming. Two-person general-sum games. Non-cooperative  $n$ -person games; Nash equilibrium points. Cooperative  $n$ -person games: the core, stable sets, Shapley value, bargaining set, kernel, nucleolus. Games without side payments. Games with infinitely many players. Economic market games.

### 9537. DYNAMIC PROGRAMMING

Spring term. Credit three hours. Three lecture-recitation periods. Prerequisite: 9560.

Dynamic programming as a computational technique for solving a wide variety of problems. Concentration on deterministic problems; the knapsack problem, the obstacle course problem, finite horizon inventory models with known demand. Introduction to Markov sequential decision problems; Howard's algorithm in the finite state and action space case.



**9539. SELECTED TOPICS IN MATHEMATICAL PROGRAMMING**

Spring term. Credit three hours. Three lecture-recitation periods. Prerequisite: 9530 and 9531.

Chosen from current research areas such as integer programming over finitely generated groups, chance-constrained games, duality theory, infinite games.

**9550. ENGINEERING ECONOMIC ANALYSIS**

Fall term. Credit three hours. Three lectures.

Use of cost information for financial reporting, cost control, and decision-making. Theory of double-entry accrual accounting. Use of costs in manufacturing: job order versus process costing; predetermined overhead rates, standard costs and variances. Modification of cost information for decision-making: cost dichotomies, profit-volume charts, direct costing, costing of joint products and by-products, economic lot sizes, use of costs in other models of operations research. Capital investment planning: the time value of money, use of interest rates, ranking procedures for proposed projects, handling of risk and uncertainty.

**9551. ADVANCED ENGINEERING ECONOMIC ANALYSIS**

Spring term. Credit four hours. Three lectures. Prerequisite: 9311 or equivalent.

Topics include: capital investment planning procedures, project ranking, interdependence of productive investment and financing decisions. Applications of linear programming to capital budgeting problems. Theory of the firm including objectives, market structure, and pricing policies. Problems of profit measurement in the decentralized firm including intensive discussion of transfer pricing.

**9560. APPLIED STOCHASTIC PROCESSES**

Spring term. Credit three hours. Two recitations, one computation period. Prerequisites: 9460 or permission of the instructor.

An introduction to stochastic processes, emphasizing basic theory and its engineering applications. The following topics are covered: second order processes, covariance function and spectral distribution, Markov chains and processes, diffusion processes, renewal theory and recurrent events, fluctuation theory, random walks, branching processes, queues, Brownian motion, and birth- and death-processes.

**9561. QUEUING THEORY**

Fall term. Credit three hours. Two recitations, one computation period. Prerequisites: 9460 and permission of the instructor.

Definition of a queuing process. Poisson and Erlang queues. Imbedded chains. Transient behavior of the systems  $M/G/1$  and  $GI/M/1$ . The general queue  $GI/G/1$ . Bulk queues. Applications to specific engineering problems such as shop scheduling, equipment maintenance, and inventory control.

**9562. INVENTORY THEORY**

Spring term. Credit three hours. Three lecture-recitation periods. Prerequisites: 9460 and permission of the instructor.

An introduction to the mathematical theory of inventory and production control with emphasis on the construction and solution of mathematical models; topics will be drawn from the recent technical literature and will include deterministic and stochastic demands; dynamic programming and stationary analyses of inventory problems; renewal theory applied to inventory

problems; multi-echelon problems; statistical problems; and production smoothing.

#### 9563. SELECTED TOPICS IN THE THEORY OF QUALITY AND RELIABILITY CONTROL

Spring term. Credit three hours. Three lectures. Prerequisite: 9470 or equivalent.

The statistical properties and derivation of some quality and reliability control procedures. Topics will include the economic design of Shewhart control charts, cumulative sum control charts, Girshick and Rubin control procedures, moving average control charts, sampling inspection by variables for percent defective, reliability estimation, and reliability growth models.

#### 9564. SEQUENTIAL DECISION AND CONTROL PROCESSES

Fall term. Credit three hours. Three lectures. Prerequisite: 9537.

This course will concentrate on Markov sequential decision models with general action and state spaces. A careful study of the underlying probabilistic structure. Finite horizon problems, total expected discounted return, optimal stopping, time-average return criteria. Study of the existence and characterization of optimal control strategies.

#### 9565. TIME SERIES ANALYSIS

Fall term. Credit three hours. Three lectures. Prerequisite: permission of the instructor.

Introduction to Hilbert space and its application to linear regression, linear prediction and estimation, and spectral analysis. Properties of martingales with application to prediction and discrimination.

#### 9569. SELECTED TOPICS IN APPLIED PROBABILITY

Either term. Credit three hours. Three lectures. Prerequisites: 9560 and permission of the instructor.

Selected topics in applied probability for advanced students. Topics will be selected from the current literature in addition to the research areas of the staff.

#### 9570. INTERMEDIATE ENGINEERING STATISTICS

Fall term. Credit three hours. Two lectures, one computation period. Prerequisite: 9370 or 9470, or permission of the instructor.

Application of statistical methods to the efficient design, analysis, and interpretation of engineering experiments; rational choice of sample size for various statistical decision procedures, and the operating characteristic curves of these procedures; curve fitting by least squares; simple, partial, and multiple correlation.

#### 9571. DESIGN OF EXPERIMENTS

Fall term. Credit four hours. Two lectures, one computation period. Prerequisite: 9470 or permission of the instructor.

Use and analysis of experimental designs such as randomized blocks, Latin squares, and incomplete blocks; analysis of variance and covariance; factorial experiments, confounding, fractional replication; statistical problems associated with finding best operating conditions; response surface analysis.

#### 9572. STATISTICAL DECISION THEORY

Fall term. Credit three hours. Three lectures. Prerequisite: 9470 or equivalent.

The general problem of statistical decision theory and its applications. The comparison of decision rules; Bayes, admissible, and minimax decision rules.

Problems involving a sequence of decisions over time, including sequential analysis. Use of the sample cumulative distribution function, and other non-parametric methods. Applications to problems in the areas of inventory control, sampling inspection, capital investment, and procurement.

#### 9573. STATISTICAL MULTIPLE-DECISION PROCEDURES

Spring term. Credit three hours. Two recitations, one computation period. Prerequisite: 9571 or permission of the instructor.

The study of multiple-decision problems in which a choice must be made among two or more courses of action. Statistical formulations of the problems. Fixed-sample size, two-stage, and sequential procedures. Special emphasis on applications to ranking problems involving choosing the "best" category where goodness is measured in terms of a particular parameter of interest. Recent developments.

#### 9579. SELECTED TOPICS IN STATISTICS

Either term. Credit three hours. Two recitations, one computation period. Prerequisite: 9470 or permission of the instructor. Offered as required.

Selected topics chosen from such areas as nonparametric statistical methods, sequential analysis, multivariate analysis.

#### 9580. DIGITAL SYSTEMS SIMULATION

Fall term. Credit four hours. Two lectures, one recitation. Prerequisites: 9481 and 9470, or permission of the instructor.

The use of a program for a digital computer to simulate the operating characteristics of a complex system in time. Discussion of problems encountered in construction of a simulation program, synchronization and file maintenance, random number generation, random deviate sampling. Programming in simulation languages. Problems in the design of effective investigations using simulation, and statistical considerations when sampling from a simulated process. Applications of simulation.

#### 9582. DATA PROCESSING SYSTEMS

Fall term. Credit three hours. One lecture, one computation period. Prerequisite: 9481 or permission of the instructor.

The design of integrated data processing systems for operational and financial control; questions of system organization, languages, and equipment appropriate to this type of application; file structures, addressing and search problems, sorting techniques; problems of multiple-remote-input, on-line data processing systems; techniques of system requirement analysis.

#### 9591. OPERATIONS RESEARCH GRADUATE SEMINAR

Both terms. Credit one hour. A weekly one-and-a-half hour meeting.

A weekly seminar devoted to presentation, discussion, and study of research in the field of Operations Research. Distinguished visitors from other universities and institutions, both domestic and foreign, as well as faculty members and advanced graduate students of the Department and the University speak on topics of current interest.

## PHYSICS

Faculty: Vinay Ambegaokar, Neil W. Ashcroft, Karl Berkelman, Hans A. Bethe, Raymond Bowers, Andrew A. Browman, Peter A. Carruthers, David G. Cassel, Geoffrey V. Chester, Robert M. Cotts, John P. Delvaille, John W. DeWire, Donald A. Edwards, Douglas B. Fitchen, Kurt Gottfried, Kenneth I. Greisen,

Donald E. Groom, Franz L. Gross, Louis N. Hand, Donald L. Hartill, Paul L. Hartman, Donald F. Holcomb, Toichiro Kinoshita, James A. Krumhansl, David M. Lee, Raphael M. Littauer, Eugene C. Loh, Herbert Mahr, Bruce W. Maxfield, Boyce D. McDaniel, N. David Mermin, Herbert F. Newhall, Jay Orear, Lyman G. Parratt, John Peoples, Robert O. Pohl, John D. Reppy, Robert C. Richardson, Edwin E. Salpeter, Albert J. Sievers, Robert H. Silsbee, Albert Silverman, Peter C. Stein, Richard M. Talman, D. Hywel White, John W. Wilkins, Kenneth G. Wilson, Robert R. Wilson, William M. Woodward, and Donald R. Yennie.

Also on the faculty, but rarely serving on graduate students' Special Committees, are typically four visiting professors and about forty Ph.D. instructors and research associates.

Field Representative: Toichiro Kinoshita, 113 Clark Hall.

**MAJOR AND MINOR SUBJECTS.** For either the M.S. or Ph.D. degree in the Field of Physics it suffices to have one minor subject, either inside or outside the Field, but, for the Ph.D. degree, the student's Special Committee may require two minors. If two minors are required, at least one must be outside the Field of Physics.

Within the Field of Physics, the possible major and minor subjects are:

#### MAJOR SUBJECTS

Physics  
Experimental Physics  
Theoretical Physics

#### MINOR SUBJECTS

Physics  
Experimental Physics  
Theoretical Physics

The major or minor subject may be *Physics* only if accompanied by a minor or major subject, respectively, outside the Field of Physics. The major subject may be *Experimental Physics* only if accompanied by *Theoretical Physics* as a minor, and may be *Theoretical Physics* only if accompanied by *Experimental Physics* as a minor.

Each student has a Special Committee that (a) represents his major and minor interests and (b) serves as an advisory and examining committee. This Special Committee consists of at least three members with at least two from the Field of Physics. The initial committee is normally appointed, but the student himself is expected to choose his "permanent" committee (to replace the appointed committee) as soon as his major and minor interests become reasonably firm. The chairman of the "permanent" committee represents the major and normally, but not necessarily, is the member who supervises the thesis.

**ADMISSION.** The large majority of entering students have completed an undergraduate physics major program including such junior-senior courses as analytical mechanics, electricity and magnetism, optics and wave motion, electronics, atom physics, thermodynamics, quantum mechanics, and solid-state and nuclear physics; some junior-senior-course laboratory work in physics is also expected. Knowledge of differential equations and of vector calculus is essential.

In the selection of new students, emphasis is on the quality of the undergraduate work and on the promise for graduate work rather than on the extent of undergraduate study in physics and related subjects. Many entering students enroll in one or more undergraduate courses to make up deficiencies.

As stated below (under "Courses of Instruction"), enrollment in the Summer Session before September admission is strongly recommended in order to allow leeway in the schedule of course work during the first year at Cornell.

Almost all students are admitted directly into the Ph.D. program. (If an

applicant's academic background in physics is either deficient or questionable, he may be admitted *provisionally* into the Ph.D. program; this is fairly common for students from foreign countries.) Some students are admitted directly as Master's candidates either for the M.S. or for the professional M.S.T. degree.<sup>1</sup> Some students in the Ph.D. program prefer to work toward the M.S. degree either as a terminal degree or on the way toward a Ph.D. degree. Most students, however, prefer to proceed directly for the Ph.D. degree.

A student who wishes to interrupt his graduate work with a leave of absence for longer than one year must apply for readmission on the same basis as a new student, i.e., he must obtain the recommendation of the Field Committee on Admissions.

**MASTER'S (M.S.) DEGREE WITHOUT A THESIS.** It is permissible in the Field of Physics to replace the normally required Master's thesis with additional courses in physics. If a student in the Ph.D. program has passed two years of graduate physics courses and then passes the Admission to Ph.D. Candidacy Examination "at the Master's level", he may be recommended for the M.S. degree without a thesis and without further examination.

**FOREIGN LANGUAGE REQUIREMENT.** No foreign language is required for either a Master's or a Ph.D. degree. However, proficiency in at least one foreign language (preferably Russian, German, or French) is very desirable; it is strongly recommended that this proficiency be acquired before graduate work is undertaken.

**EXAMINATION STRUCTURE IN PHYSICS.** *For an M.S. degree:* either the Master's Final Examination or the Admission to Ph.D. Candidacy Examination.

*For a Ph.D. degree:* (a) the Qualifying Examination (required specifically by the Field of Physics) taken normally at the beginning of the second year of graduate work, (b) the comprehensive Admission to Ph.D. Candidacy Examination taken normally after the second year of graduate work, and (c) the Ph.D. Final Examination. For a few students making especially good progress their first year, the Qualifying Examination is oral only; for all others it is written *and* oral; the written part is administered once each year, in September just before the start of classes. The Qualifying Examination may be taken a second time (within a year), but only one re-examination is allowed. The Ph.D. Final Examination is oral and is confined to the subject of the thesis.

**ASSISTANTSHIPS AND FELLOWSHIPS.** Essentially all first- and second-year graduate physics students hold either a teaching appointment, a fellowship, or both (see below). The faculty emphasizes the training importance of teaching experience and encourages *all* qualified students to teach at least one year and preferably two years. Regular teaching appointments involve about sixteen hours per week, usually in undergraduate classrooms and laboratories or as readers. Any fellowship holder who wishes it, and whose fellowship conditions allow it, may have a teaching appointment, usually with reduced duties and with a reduced (additional) stipend.

Most third- and higher-year students are either fellows, research assistants, or both. Regular research appointments involve nominally 20 hours per week of work closely allied to the student's doctoral thesis which is normally undertaken at the beginning of the third year of graduate work.

<sup>1</sup> See page 27. For information about the objectives and requirements of the M.S.T. degree with a concentration in physics, write directly to Professor Kenneth I. Greisen, Department of Physics, 111 Clark Hall.

Holding a teaching or a research appointment does not significantly delay the completion of the requirements for an advanced degree.

Most assistantships and fellowships are for the academic year. Very few assistantships are available for first- or second-year students during the summers, although almost all higher-year students hold two-month summer research assistantships. Many fellowships are for twelve months (rather than nine) or may be extended to twelve; the twelve-month tenure is of course recommended.

**FURTHER INFORMATION.** A copy of the brochure *Graduate Study in Physics at Cornell* (containing additional information for the prospective graduate student), a reference list of publications from the Department of Physics for the preceding year, and/or a copy of application materials for an assistantship in physics, may be obtained by writing to the Chairman of the Department of Physics, Clark Hall.

## Research Opportunities

**THEORETICAL PHYSICS.** Many-body theory, theory of superconductors, theory of metallic state, superfluidity, statistical mechanics and irreversibility, phonon physics and transport processes, low-temperature physics, electrodynamic phenomena and defects in solids, plasma physics, dispersion relations and strong interactions—high energy limits, “bootstrap” dynamics, models of reaction processes—internal symmetries and their connection with strong interaction dynamics, current algebra, quantum electrodynamics, quantum field theory and renormalization, astrophysics, and stellar structure. About half of the theory group is primarily associated with the Laboratory of Nuclear Studies and about half primarily with the Laboratory of Atomic and Solid State Physics; however, continual interaction takes place within both the entire group of theorists and with all the experimentalists.

**EXPERIMENTAL HIGH-ENERGY NUCLEAR RESEARCH.** Photo-production processes involving intermediate-mass mesons and hyperons, energy levels of excited states of the proton, detailed study of the structure of the proton, synchrotron radiation, gamma ray interactions with matter, Compton scattering, photo-disintegration of nuclei, cosmic rays including air showers and methods of detection of neutral primary radiations, properties of elementary particles, and high-energy interactions. Large machine shop and electronics shop; 2-Gev and 10-Gev electron synchrotrons, etc. Cornell staff and students also participate in research with the AGS 30-Gev proton synchrotron at Brookhaven.

**EXPERIMENTAL ATOMIC AND SOLID-STATE PHYSICS.** Phonon physics, superconductivity, optical spectroscopy, low-temperature physics, magneto-plasma waves, spin resonance, x-ray emission and absorption spectra, electron diffraction, thermal conductivity, and spin relaxation. Large machine shop and glass-blowing shop; several large stable DC magnets, superconducting solenoids, vacuum UV spectrographs, IR to UV monochromators, spin resonance spectrometers, and x-ray spectrometers. Available through association with the Materials Science Center of Cornell University are: central facilities for electronics, crystal growing, cryogenics (a millidegree facility), analytical chemistry, technical operations, high pressure, x ray and metallography, crystal irradiation and electron microscopy.

**SPACE PHYSICS.** Astrophysics, stellar structure, cosmic rays, radio astronomy, and upper atmosphere. Facilities are available through the Cornell Center for Radiophysics and Space Research; these include a lunar surface laboratory, radio astronomy and ionospheric laboratories, and the radio telescope in the Arecibo Ionospheric Laboratory in Puerto Rico.

**APPLIED PHYSICS, MATERIALS SCIENCE, ASTRONOMY AND SPACE SCIENCES, APPLIED MATHEMATICS, ETC.** Many of the faculty of the Field of Physics are also members of other Fields and Centers, and graduate students are often indistinguishable by Fields in consequence of the various combinations of interests (majors and minors). Faculty and students benefit from the cross-boundary informalities and especially from the availability of much more extensive research facilities.

## Courses

Courses at the undergraduate level are listed in the *Announcement of the College of Arts and Sciences*. Several of the junior-senior courses are frequently taken by graduate students whose backgrounds are somewhat deficient. Such courses are Physics 319, 325, 326, 342, 360, 431, 432, 443, 444, and 454.

Graduate physics courses are numbered 500 or higher; they are listed below but are preceded by a few popular undergraduate senior courses.

Almost all first-year graduate physics students take three courses each term; occasionally, but not normally, a student who does not hold a teaching or research appointment takes four courses. Students are encouraged to complete their "core" courses within one calendar year for the Master's and within two calendar years for the Ph.D.; the core courses are those to be taken before the Master's Final or the Admission to Ph.D. Candidacy Examination. To expedite completion of requirements for the degree, all students are urged to take Physics 510 during the summer preceding their first academic year, and, if Ph.D.-bound, Physics 574 during the summer following their first year.

A typical first-year program for a Ph.D. or M.S. student having adequate preparation, a program without much leeway, is the following (P = Physics and M = Mathematics):

First term: P-510; P-561; M-415.

Second term: P-562; P-572; M-416 or M.S. thesis.

Most students find this program uncomfortably demanding, in addition to the leeway problem; it bears repetition that they are strongly advised to take P-510 during the "presummer" period.

Supplementing the formal courses, students and staff meet over coffee or tea at weekly physics colloquia and topical seminars. For first-year graduate students a special seminar is held biweekly to acquaint the newcomers with Cornell and the Physics Department. Every graduate student is allotted a study desk in one of the physics buildings. He is encouraged to assume the full life of the community of active physicists as soon as possible.

### 431-432. INTRODUCTORY THEORETICAL PHYSICS I AND II

Throughout the year. Credit four hours a term. Prerequisites: (a) 207-208; for 432, either 431 or 303 and 322, and (b) coregistration in Mathematics 421-422 or consent of the instructor. Primarily for graduate students in a science other than physics (e.g., in chemistry, engineering, or biology) who wish a shortcut to more advanced courses (e.g., to 443, 561, 562 or 572). M W F S 11:15. Fall term, Mr. Bethe. Spring term, professor to be appointed.

*Fall term.* Emphasis is on particle mechanics and potential theory. Topics include Newtonian mechanics, Lagrange's equations, Hamilton's equations, central forces, rigid-body motion, electrostatics, boundary-value problems, and Maxwell's equations. At the level of *Mechanics*, second edition, by Symon, and of *Foundations of Electromagnetic Theory* by Reitz and Milford.

*Spring term.* Emphasis is on waves and radiation. Topics include normal modes, waves in mechanical media, electromagnetic waves, normal modes of the electromagnetic field, reflection, refraction, interference, diffraction, dispersion, wave guides, and radiation from an accelerated charge. At the level of *Classical Electromagnetic Radiation* by Marion.

#### 443. ATOMICS AND INTRODUCTORY QUANTUM MECHANICS

Fall term. Credit four hours. Prerequisites: 305, 319, and 325, or 432, and Mathematics 316 or 421, or consent of the instructor. Very few students should take Physics 572 before taking this course or its equivalent. T Th S 10:10 and M 9:05 or 2:30. Messrs. Bowers and Groom.

Difficulties with the classical interpretations of atomic properties are resolved in terms of quantum mechanics. At the level of *Introduction to Quantum Theory* by Park.

#### 444. NUCLEAR AND HIGH-ENERGY PARTICLE PHYSICS

Spring term. Credit four hours. Prerequisite: 443 or consent of the instructor. M W F 9:05 and F 1:25. Messrs. Orear and Hartill.

Behavior of high-energy particles and radiation; elementary particles; basic properties of nuclei; nuclear reactions; nuclear forces; cosmic rays; general symmetries and conservation laws of nature. At the level of *Nuclei and Particles* by Segre.

#### 454. INTRODUCTORY SOLID-STATE PHYSICS

Spring term. Credit four hours. Prerequisite: 443 or Chemistry 593, or consent of the instructor. T Th S 10:10 and Th 2:30 or 3:35. Mr. Wilkins.

A semiquantitative introduction to modern solid-state physics, including lattice structure, lattice vibrations, thermal properties, electron theory of metals and semiconductors, magnetic properties, and superconductivity. At the level of *Introduction to Solid State Physics*, third edition, by Kittel.

#### 500. INFORMAL GRADUATE LABORATORY

Either term. (Also offered during the summer.) Credit one to three hours a term. Associated with the Physics 510 laboratory. Primarily for graduate students who have had at least the equivalent of 310 or 360 but who do not have the prerequisites for 510. T W or Th F 1:25-4:25. Fall term: Messrs. Hartman, Heybey, Cuykendall, Hartill, Littauer, Reppy, Stein, Webb, and Woodward. Spring term. Messrs. Hartman, Cassel, Cuykendall, Mistry, Siegel, and Talman.

#### 505-506. DESIGN OF ELECTRONIC CIRCUITRY

Throughout the year. Credit two hours each term. Prerequisites: 360, Mathematics 315, and familiarity with complex representation of a-c signals, or consent of the instructor. Course 505 is prerequisite to 506. T Th 9:05. Mr. Joseph and staff.

Circuit techniques and design in electronic measurement and instrumentation with emphasis on pulse waveforms. At the level of *Pulse Electronics*, 1965, by Littauer.



## 510. ADVANCED EXPERIMENTAL PHYSICS

Either term. (Also offered during the summer.) Credit three hours per term. Prerequisites: 410 and 443 or consent of the instructor. At least one term of 510 is ordinarily required of every graduate physics student during his first year at Cornell. T W or Th F 1:25-4:25. Instructing staff same as for Physics 500.

About seventy different experiments are available among the subjects of mechanics, acoustics, optics, spectroscopy, electrical circuits, electronics and ionics, heat, x rays, crystal structure, solid state, cosmic rays, and nuclear physics. The student is expected to perform four to eight experiments selected to meet his individual needs. Stress is laid on independent work.

## 520. PROJECTS IN EXPERIMENTAL PHYSICS

Either term. Credit three hours per term. Prerequisites: 510 and consent of the instructor. Hours to be arranged. Mr. Littauer and staff.

Projects of modern topical interest that involve some independent development work by the student. Opportunity for more initiative in experimental work than is possible in 510. One or two projects in different areas typically comprise a term's work (e.g., with the Cornell 2-Gev synchrotron, or with a liquid helium cryostat, or with both.)

## 561-562. THEORETICAL PHYSICS I AND II

Throughout the year. Credit four hours each term. Prerequisites: 319 and 325, or 432, and coregistration in Mathematics 415 or 423, or consent of the instructor. Course 561, and either 443 or coregistration in 572, are prerequisite to 562. M 1:25 and T Th S 11:15. Fall term: Mr. Gross. Spring term: Mr. Chester.

*Fall term.* Mechanics (about 7 weeks): variational principles, Lagrangian mechanics with applications, Hamiltonian mechanics and Poisson brackets, small vibrations and normal modes, and symmetry principles. Electrodynamics (about seven weeks): Maxwell's equations, electromagnetic potentials, stress energy, wave guides, Fresnel theory, and relativity. At the level of *Mechanics* by Landau and Lifshitz, and of *Electricity and Magnetism* by Jackson.

*Spring term.* Electrodynamics (about 6 weeks): radiation, Lienard-Wiechert potentials, multipoles, relativity (continued), and relativistic applications. Statistical physics (about eight weeks): laws of thermodynamics, introduction to phase change, ensemble theory, thermodynamic fluctuations, Fermi-Dirac and Einstein-Bose statistics with applications, transport phenomena, and interacting systems. At the level of *Electricity and Magnetism* by Jackson, and of *Statistical Physics* by Landau and Lifshitz.

## 572. QUANTUM MECHANICS

Either term. Credit four hours. Prerequisites: 443, 561 (or 432 with special permission), and at least coregistration in Mathematics 415 or 423, or consent of the instructor. M W F 11:15 and S 9:05. Fall term: Mr. K. Wilson. Spring term: Mr. Krumhansl.

Principles of wave mechanics. Illustrative solutions of the Schrodinger equation, scattering, Dirac's formulation of quantum mechanics, transformation theory, and approximation methods. Symmetries: angular momentum, spin, the exclusion principle. At the level of *Quantum Mechanics*, Vol. I and part of Vol. II, by Messiah.

## 574. INTERMEDIATE QUANTUM MECHANICS

Spring term. (Also offered during the summer.) Credit four hours. Prerequisites:

572 and at least coregistration in 562 and in Mathematics 416, or consent of the instructor. Required of all Ph.D. majors in *Theoretical Physics*. M W F S 10:10. Mr. Bethe.

Discussion of various applications of quantum mechanics such as collision theory, theory of spectra of atoms and molecules, theory of solids, emission of radiation, and relativistic-quantum mechanics. At the level of *Quantum Mechanics of One- and Two-Electron Atoms* by Bethe and Salpeter.

#### 612. EXPERIMENTAL ATOMIC AND SOLID-STATE PHYSICS

Spring term. Credit three hours. Prerequisites: 510, 561, and 562, or consent of the instructor. M W F 2:30. Mr. Fitchen and staff.

Lectures on techniques and design principles, with emphasis on the study of solids by their interactions with electromagnetic fields. Topics include sources and detectors, scanning and resonance techniques, signal-processing, sample characterization, and environmental control. Illustrative examples from the recent literature are studied in detail.

#### 614. EXPERIMENTAL HIGH-ENERGY PHYSICS

Spring term. Credit three hours. Prerequisites: 510, 561, and 562, or consent of the instructor. Two lectures and one problem discussion section per week. T Th F 1:25. Mr. Browman and staff.

Design principles of high-energy apparatus: accelerators, beam transport, detection systems, etc., with examples of their applications. Practice in the use of relativistic kinematics. Statistical analysis in the design and interpretation of experiments. Discussion of the pitfalls encountered in actual experiments, with examples from the recent literature.

#### 635. SOLID-STATE PHYSICS I

Fall term. Credit three hours. Prerequisites: 572 and statistical physics at the level of 562, or consent of the instructor. Expected of every Ph.D. *Experimental Physics* major or minor. T Th S 11:15. Mr. Sievers.

An introduction to solid-state physics including studies of lattice vibrations, the electronic structure of metals and insulators, with applications to electrical, thermal, and transport properties. At the level of *Principles of the Theory of Solids*, 1964, by J. M. Ziman.

#### 636. SOLID-STATE PHYSICS II

Spring term. Credit three hours. Prerequisite: 635 or consent of the instructor. T Th S 11:15. Mr. Ashcroft.

The concepts developed in 635 are extended and applied to a survey of some of the following: band theory and the Fermi surface in metals, localized states, magnetism, neutron and light scattering, and phenomenological superconductivity.

#### 645. NUCLEAR PHYSICS

Fall term. Credit three hours. Prerequisite: 572 or consent of the instructor. Expected of every Ph.D. *Experimental Physics* major or minor. M W F 11:15. Mr. Hand.

Properties of nuclei, detection of particles, alpha decay, fission and thermonuclear reactions, gamma decay, beta decay, two-nucleon systems, nuclear models, and nuclear reactions. At the level of *Nuclear Interactions*, 1964, by DeBenedetti.

#### 646. HIGH-ENERGY PARTICLE PHYSICS

Spring term. Credit three hours. Prerequisite: 574 or 645 or consent of the instructor. M W F 11:15. Mr. Silverman.

The physics of nucleons, mesons, and strange particles from an experimental point of view. High-energy phenomena, as opposed to classical nuclear physics, will be stressed. At the level of *An Introduction to Elementary Particles* by Williams.

NOTE: In courses above 650 the final grades will be only S or U.

#### 651. ADVANCED QUANTUM MECHANICS

Fall term. Credit three hours. Prerequisite: 574 or consent of the instructor. M W F 10:10. Mr. Ambegaokar.

Relativistic quantum mechanics with emphasis on perturbation techniques. Extensive applications to quantum electrodynamics. Introduction to renormalization theory. At the level of *Relativistic Quantum Mechanics* by Bjorken and Drell.

#### 652. QUANTUM FIELD THEORY

Spring term. Credit three hours. Prerequisite: 651 or consent of the instructor. M W F 10:10. Mr. K. Wilson.

Canonical field theory, model field theories, Green's functions, renormalization. Introduction to analytic properties of scattering amplitudes and dispersion relations. Applications to strong interactions. At the level of *Relativistic Quantum Fields* by Bjorken and Drell.

#### 653. STATISTICAL PHYSICS

Fall term. Credit three hours. Prerequisites: 562 and 572, or consent of the instructor. T Th S 10:10. Mr. Wilkins.

A survey of topics in contemporary statistical physics, such as the Boltzmann equation, plasmas, sound propagation, phenomenological Fermi liquid theory, critical phenomena of simple fluids and ferromagnets, classical fluids, introduction to Kubo formulae and Green's functions, and superfluids. At the level of *Statistical Physics* by Landau and Lifshitz.

#### ELECTRICAL ENGINEERING 4661. KINETIC EQUATIONS

Fall term. Credit three hours. Prerequisites: Physics 561 and 562, or permission of the instructor. Mr. Liboff.

#### 654. THEORY OF MANY-PARTICLE SYSTEMS

Spring term. Credit three hours. Prerequisites: 635 and 653, or consent of the instructor. T Th S 10:10. Mr. Mermin.

The equilibrium and transport properties of microscopic systems of many particles are studied at zero and finite temperatures. Thermodynamic Green's function techniques are introduced and applied to such topics as normal and superconducting Fermi systems, superfluidity, magnetism, and insulating crystals.

#### 657. THEORY OF NUCLEI

Not offered in 1968-69; will be offered in 1969-70 on sufficient demand. Fall term. Credit three hours. Prerequisites: 574 and 645, or consent of the instructor. Offered in alternate years and only if registration exceeds nine students. M W F 9:05. Mr. Bethe.

#### 661. HIGH-ENERGY PHENOMENA

Fall term. Credit three hours. Prerequisite: 651 or consent of the instructor. Offered only if registration exceeds nine students. M W F 10:10. Mr. Carruthers.

Topics of current interest in the theory of strong interactions. At the level of *Dispersion Relations* by Klein.

## 666. TOPICS IN THEORETICAL ASTROPHYSICS

Not offered in 1968-69; will be offered in 1969-70.

Spring term. Credit three hours. Prerequisite: graduate student status with a good background in physics, or consent of the instructor. This course and Astronomy 560 alternate by year. M Th F 1:25. Mr. Salpeter.

Typical topics are: theory of stellar structure, theory of stellar atmospheres, and theories of interstellar medium. Topics and their treatment will vary from year to year.

## 680. SPECIAL TOPICS

Either term. Credit one to three hours a term. Upon sufficient demand, seminars will be arranged in topics not covered in regular courses.

Typical topics are: group theory, analyticity in particle physics, weak interactions, superfluids, stellar evolution, plasma physics, cosmic rays, general relativity, low-temperature physics, x-ray spectroscopy or diffraction, magnetic resonance, etc.

1968 Fall term: 680A, Finite Groups, Mr. Ashcroft. 1969 Spring term: 680B, Theory of Cornell-LNS Experiments, Mr. Yennie; 680C, Group Theory for Particle Physics, Mr. Kinoshita. (Topics for 1969-70 will be announced later.)

## 690. INDEPENDENT STUDY IN PHYSICS

Either term. Credit one to three hours a term. Special graduate study in some branch of physics, either theoretical or experimental, under the direction of any professional member of the staff. Permission of the staff member under whose direction the work is to be done *must be obtained before registration*.

## STATISTICS

Faculty: Robert E. Bechhofer, Isadore Blumen, Lawrence D. Brown, Roger Farrell, Walter T. Federer, Harry Kesten, Jack Kiefer, Philip J. McCarthy, Narahari U. Prabhu, Douglas S. Robson, Shayle R. Searle, Frank L. Spitzer, Howard M. Taylor 3d, N. Scott Urquhart, Lionel Weiss, Jacob Wolfowitz.

Field Representative: Isadore Blumen, 360 Ives Hall.

## MAJOR SUBJECT

Statistics

## MINOR SUBJECTS

Provisions for minoring in statistics are given in the descriptions of the Fields of Operations Research, Industrial and Labor Relations, Mathematics, and Plant Breeding and Biometry contained in the *Announcements* of the various areas of the Graduate School.

**ADMISSION REQUIREMENTS.** Since one of the principal aims of graduate work in the Field of Statistics is that of training individuals who will have a thorough knowledge of the theoretical basis of modern statistical method and will have demonstrated ability to make significant contributions to this theory, applicants should ordinarily have obtained nearly the equivalent of an undergraduate major in mathematics. It is strongly recommended that applicants resident in the United States during the year before entering the Graduate School present scores on the Graduate Record Examination Aptitude Test.

**LANGUAGE REQUIREMENT.** There is no foreign language requirement for the M.S. degree. A candidate for the Ph.D. degree must demonstrate reading ability in one language besides English, chosen from among French, German, or Russian.

**PROGRAM OF STUDY.** A student majoring in the Field of Statistics must complete a graduate sequence of courses in mathematical statistics which has been approved by his Special Committee. Other course work required of majors in statistics will be chosen from among the offerings, as listed below, of the members of the Field. A doctoral student in the Field of Statistics ordinarily has two minor subjects but may, in consultation with the chairman of his Special Committee, choose to work in one minor subject. One minor subject will often be in an area of interest to the student in which the methods of statistics find extensive application. A second minor is usually devoted to mathematics, computing, or a similar subject.

**PH.D. EXAMINATIONS.** In addition to the Admission to Candidacy Examination, which will ordinarily be administered by the student's Special Committee during or at the end of the third year of graduate study, and the Final Examination on the thesis, the student will be given a qualifying examination. This examination will occur shortly after the first year of graduate study. It will serve to determine the ability of the candidate to pursue doctoral studies and to assist the Special Committee in developing a program of study for the candidate.

## Teaching and Research Interests of the Faculty

In extremely broad terms, the teaching and research interests of faculty members are in the following general areas: biological applications of probability and statistics (Federer, Robson, Searle, Urquhart); engineering and operations research applications of probability and statistics (Bechhofer, Prabhu, Taylor, Weiss); mathematical theory of probability and statistics (Brown, Farrell, Kesten, Kiefer, Spitzer, Wolfowitz); social science applications of probability and statistics (Blumen, McCarthy).

Some of the more specific areas of current interest are: analysis and probability theory (Kesten, Spitzer); design and analysis of experiments (Bechhofer, Federer, Kiefer, Robson, Searle, Urquhart, Wolfowitz); high speed computing (Searle); mathematical theory of statistics (Farrell, Kiefer, Wolfowitz); multiple decision procedures (Bechhofer); multivariate analysis (Blumen, Urquhart); nonparametric statistics (Blumen, Weiss); queuing and inventory theory (Prabhu); sampling theory (McCarthy, Robson); sequential sampling methods (Kiefer, Weiss); statistical control theory (Taylor); statistical genetics (Federer, Robson, Searle).

## Courses

Descriptions of the following courses may be found in the *Announcements* of the various areas of the Graduate School under the Fields with which they are identified; in those sections reference is also made to several advanced seminars, both formal and informal, the content of which varies from year to year.

## Advanced Undergraduate and Master's Level Courses

### OPERATIONS RESEARCH

9460. INTRODUCTION TO PROBABILITY THEORY WITH ENGINEERING APPLICATIONS

9470. INTRODUCTION TO STATISTICAL THEORY WITH ENGINEERING APPLICATIONS

9512. STATISTICAL METHODS IN QUALITY AND RELIABILITY CONTROL

9570. INTERMEDIATE ENGINEERING STATISTICS

### INDUSTRIAL AND LABOR RELATIONS

310. DESIGN OF SAMPLE SURVEYS

311. STATISTICS II

410. TECHNIQUES OF MULTIVARIATE ANALYSIS

411. STATISTICAL ANALYSIS OF QUALITATIVE DATA

### MATHEMATICS

371. BASIC PROBABILITY

472. STATISTICS

### PLANT BREEDING AND BIOMETRY

410-411. MATHEMATICAL AND STATISTICAL MODELS IN BIOLOGY

417. MATRIX ALGEBRA IN BIOLOGY AND STATISTICS

510. STATISTICAL METHODS I

511. STATISTICAL METHODS II

## Advanced Master's and Doctor's Level Courses

### OPERATIONS RESEARCH

9560. APPLIED STOCHASTIC PROCESSES

9561. QUEUING THEORY

9564. STATISTICAL ASPECTS OF RELIABILITY ANALYSIS

9571. ADVANCED INDUSTRIAL AND ENGINEERING STATISTICS

9572. STATISTICAL DECISION THEORY

9573. STATISTICAL MULTIPLE DECISION PROCEDURES

## INDUSTRIAL AND LABOR RELATIONS

610. ECONOMIC AND SOCIAL STATISTICS

614. THEORY OF SAMPLING

## MATHEMATICS

571. PROBABILITY

572. STATISTICAL INFERENCE

574. ADVANCED PROBABILITY

575. INFORMATION THEORY

673. ANALYSIS OF VARIANCE

674. DESIGN OF EXPERIMENTS

675. STATISTICAL ESTIMATION

676. DECISION FUNCTIONS

677-678. STOCHASTIC PROCESSES

## PLANT BREEDING AND BIOMETRY

513. DESIGN OF EXPERIMENTS I

514. DESIGN OF EXPERIMENTS II

517. LINEAR ESTIMATION AND TESTS OF HYPOTHESIS

518. SPECIAL TOPICS IN SEQUENTIAL SAMPLING, BIOASSAY  
NONPARAMETRIC STATISTICS, ETC.

519. STATISTICAL GENETICS

## THEORETICAL AND APPLIED MECHANICS

Faculty: Kyle T. Alfriend, Henry D. Block, B. A. Boley, Harry D. Conway, Edmund T. Cranch, Constantine Dafermos, Michael D. Greenberg, Herbert H. Johnson, Richard H. Lance, Geoffrey S. S. Ludford, John R. Moynihan, Yih-Hsing Pao, Richard H. Rand, David N. Robinson.

Visiting Professor: Stephen A. Thau, Illinois Institute of Technology.

Field Representative: Yih-Hsing Pao, 237 Thurston Hall.

## MAJOR AND MINOR SUBJECTS

Fluid Mechanics

Mechanics of Materials

Solid Mechanics

The graduate program in mechanics emphasizes fundamental understanding of the newest developments in engineering and applied science. Graduate students may pursue in depth mechanics of liquids, gases, particles, rigid and deformable solids and related areas of materials, mathematics, and physics. The analytical and experimental nature of the studies encourages research that cuts across various fields. Graduate students pursue programs in the following areas of specialization: (1) space mechanics, including research on trajectories and orbits of space vehicles and satellites as well as the theory of light-weight, thin-walled structures; (2) wave propagation in solids, with research on the dynamic response of plates, structures, and machine elements; (3) structural mechanics, including static and dynamic loading, vibrations, and buckling; (4) theory of elasticity and plasticity; (5) theoretical fluid mechanics, with research in magnetohydrodynamics.

The flexibility of the M.S. and Ph.D. programs in mechanics permits students to draw on several divisions of the University for supporting work in pure and applied science. Graduate students in theoretical and applied mechanics and applied mathematics find these allied subjects of interest: mathematics, structures, engineering physics, servomechanisms, machine design, aerospace engineering, soil mechanics, and physics. To encourage the development of broad interests and skills a student normally is expected to select his two minors from approved subjects in other fields.

Students whose major is engineering, physics, or applied mathematics are encouraged to apply for admission. The Field basically requires a mature and sound background in mechanics and mathematics but expects the applicant to satisfy no additional formal entrance qualifications beyond those of the Graduate School. (See Admission, pages 6-7.)

Prior to the Admission to Candidacy Examination, students enrolled in the Ph.D. program in the Field of Theoretical and Applied Mechanics are required to take a qualifying examination administered by the entire faculty. This examination is usually taken at the end of the first semester in residence. A description of the Admission to Candidacy and Final Thesis Examinations, both required by the Graduate School, may be found on page 12 of this *Announcement*.

The Field of Theoretical and Applied Mechanics requires that each doctoral candidate demonstrate reading ability in one language other than his native language. Examination policy for proficiency is set by the Language Board of the Graduate School. The language selected must be approved by the Special Committee.

The Field of Theoretical and Applied Mechanics regards teaching experience as an essential part of the academic training of all doctoral candidates and hence makes such experience a requirement for the degree. Students admitted with advanced standing may receive credit for teaching experience acquired elsewhere.

Financial aid for students in the Field consists of University fellowships, teaching fellowships in the Department of Theoretical and Applied Mechanics, and a limited number of research assistantships in the same Department.



## Courses

### 1157. BIONICS AND ROBOTS

Fall term. Credit three hours. Prerequisites: Elementary Differential Equations, Linear Algebra and Probability or consent of instructor. Open to undergraduates or graduates. Mr. Block.

Engineering applications of strategies and tactics of biological systems. Machines that learn. Artificial intelligence. Cybernetics, information and adaptive control. Reliable systems from unreliable components. Self-organizing systems. Features in patterns. Neural nets, perceptrons, threshold logic, madelines. Brain models. Behavior models. Machines for proving theorems, playing games, navigating, exploring. Problems of sensors, perception recognition and recall. Problems of a machine to learn concepts, English, natural environments. Machine translation. Heuristic programming. Automata, pure and applied. Robots, hardware and software. Self-reproducing and self-repairing machines; models for embryology, development and evolution. Introduction to algebraic linguistics, Turing machines and computability, Gödel's theorem, the Euler-Diderot Metatheorem.

### 1159. EXPERIMENTAL MECHANICS

Fall term. Credit three hours. Graduate students and qualified undergraduates. Messrs. Robinson and Pao.

The student is expected to perform four to six experiments selected to meet his individual interests. Available experiments include: elastic waves in rods, viscoelastic waves and internal damping, linear vibrations of beams and plates, non-linear response of elastic plates, two- and three-dimensional photoelasticity, plastic response of structures, magnetoelastic buckling of a beam-plate, gyroscopic motion, linear oscillators and analog computers.

### 1160. CONTINUUM MECHANICS

Fall term. Credit three hours. Three lectures. Graduates and qualified undergraduates. Mr. Dafermos.

A unified approach to the theory of continuous media based on thermodynamic and invariant principles. Kinematics of the continuum, stress hypothesis, uniqueness, constitutive equations. Special topics and examples from finite elasticity theory, the Navier-Stokes fluid and plasticity.

### 1162. VIBRATION OF ELASTIC SYSTEMS

Spring term. Credit four hours. Three lectures and one laboratory. Graduates and qualified undergraduates. Offered alternately with 1175.

Review of vibration of linear lumped systems with emphasis on matrix methods and transient phenomena. Free and forced vibration of continuous systems including strings, rods, beams, membranes, and plates. Waves in rods and beams. Orthogonality conditions and application of generalized functions. Rayleigh-Ritz method. Mathieu function and dynamic instability of strings, columns and other elastic systems. Nonlinear phenomena.

### 1163. APPLIED ELASTICITY

Fall term. Credit three hours. Three lectures. Graduates and qualified undergraduates. Mr. Conway.

Analysis of thin curved bars. Plane stress and plane strain in the circular cylinder, effects of pressure, rotation, and thermal stress. Small and large deflection theory of plates, classical and approximate methods. Strain-energy methods. Symmetrically loaded thin cylindrical shell. Torsion of thin-walled

members. A first course in the mechanics of elastic deformable bodies with structural applications.

#### 1164. THEORY OF ELASTICITY

Spring term. Credit three hours. Three lectures. Offered alternately with 1165. Mr. Conway.

General analysis of stress and strain. Plane stress and strain. Airy's stress function solutions using Fourier series, Fourier integral, and approximate methods. St. Venant and Michell torsion theory. Simple three-dimensional solutions. Bending of prismatical bars. Axially loaded circular cylinder and half space.

#### 1165. MATHEMATICAL THEORY OF ELASTICITY

Spring term. Credit three hours. Three lectures. Offered alternately with 1164. Mr. Dafermos.

Development in tensor form of the basic equations of large deformation elasticity; solution of certain large deformation problems. Linearization to infinitesimal elasticity. Boussinesq-Papkovich potentials and their application to three-dimensional problems; contact problems; plane stress by method of Muskhelishvili; application of conformal mapping; Cauchy integral techniques in elasticity; torsion problems.

#### 1166. STRESS WAVES IN SOLIDS

Spring term. Credit three hours. Three lectures. Offered alternately with 1168. Mr. Robinson.

General equations of elastodynamics. Waves in extended elastic media. Reflection and refraction of waves. Surface waves and waves in layered media. Vibrations and waves in strings, rods, beams and plates. Dispersion in mechanical wave-guides. Transient loads. Scattering of elastic waves and dynamical stress concentration. Waves in anisotropic media and viscoelastic media.

#### 1168. THEORY OF PLASTICITY

Spring term. Credit three hours. Three lectures. Graduate students and qualified undergraduates. Offered alternately with 1166. Mr. Robinson.

Theory of inelastic behavior of materials. Plastic stress-strain laws, yield criteria and flow laws. Flexure and torsion of bars, thick-walled cylinders, metal forming and extrusion, stress analysis in metals and soils. Limit analysis of beams, plates and shells. Shakedown. Selected topics in dynamic plasticity.

#### 1169. THERMAL STRESSES

Fall term. Credit three hours. Graduate students and qualified undergraduates. Mr. Boley.

A treatment of the behavior of solids and structures at elevated temperatures. Thermomechanical coupling, inertia effects. Review of heat conduction in solids. Thermally induced vibrations. Elastic and inelastic stress analysis. Thermal buckling.

#### 1170. ADVANCED DYNAMICS

Fall term. Credit three hours. Three lectures. Graduate students and qualified undergraduates. Mr. Rand.

Newton's equations for a system of particles, Lagrange's equations, Hamilton's principle, two-body problem, particle motion in non-Newtonian frames, rigid body motion, Euler's equations, tops, gyroscopes, variational principles of mechanics.

**1172. SPACE FLIGHT MECHANICS**

Spring term. Credit three hours. Three lectures. Graduate students and qualified undergraduates. Mr. Alfriend.

Gravitational potential of the earth; two-body problem; three-body problem; restricted three-body problem; Jacobi's integral; Hill curves; libration points and stability. Lagrange's planetary equations; effect of oblate earth, atmospheric drag and solar radiation on satellite orbits; satellite attitude control; orbital transfer and orbital maneuvers; rendezvous problems.

**1175. NONLINEAR VIBRATIONS**

Spring term. Credit three hours. Prerequisite: 1162 or equivalent. Offered alternately with 1162. Mr. Rand.

Perturbation and iteration methods, phase-plane analysis, limit cycles, Lyapunov stability, Floquet theory, Mathieu's equation, graphical methods, method of Krylov-Bogoliubov. Nonlinear vibrations of a continuous system.

**1180. METHODS OF APPLIED MATHEMATICS I**

Fall term. Credit three hours. Three lectures. Graduate students or undergraduate students with consent of instructor. Mr. Greenberg.

Ordinary differential equations; series; orthogonal functions and Sturm-Liouville theory; Fourier transform; functions of several real variables; vector fields and integral theorems; matrices; partial differential equations. Development is based upon applications wherever possible.

**1181. METHODS OF APPLIED MATHEMATICS II**

Spring term. Credit three hours. Three lectures. Prerequisite: 1180 or the equivalent. Mr. Greenberg.

Continuation of partial differential equations; Green's function; Fourier and Laplace transforms; complex variables; calculus of variations; tensor analysis. Development based largely upon applications; more so than in 1180.

**1182. METHODS OF APPLIED MATHEMATICS III**

Fall term. Credit three hours. Three lectures. Prerequisite: 1181 or equivalent. Mr. Thau.

Application of advanced mathematical techniques to engineering problems. Conformal mapping; complex integral calculus; Green's function; integral transforms; asymptotics including steepest descent and stationary phase; Wiener-Hopf technique; general theory of characteristics; perturbation methods; singular perturbations including P.L.K. method and boundary layers. Development will be in terms of problems drawn from vibrations and acoustics, fluid mechanics and elasticity, heat transfer, electromagnetics.

**1183. METHODS OF APPLIED MATHEMATICS IV**

Spring term. Credit three hours. Three lectures. Prerequisite: 1182 or equivalent. Mr. Thau.

More extensive treatment of 1182 in same spirit. Topics include: method of matched asymptotic expansions, W.K.B. approximation; Hilbert-Schmidt and Fredholm theories of integral equations; singular integral equations. Wiener-Hopf equations with application to finite interval, Carleman equation and its generalization, effective approximations; further methods in partial differential equations, slot problems.

**1184. NUMERICAL METHODS IN ENGINEERING**

Spring term. Credit four hours. Prerequisite: 1181 or equivalent. Mr. Block.

Methods for obtaining numerical solutions to problems arising in engineer-

ing. Linear and nonlinear mechanical systems. Ordinary and partial differential equations, initial value problems, boundary value problems, eigenvalue problems, extrema, calculus of variations. Function-space methods. Applications to vibrations, diffusion, heat transfer, wave propagation, membranes, plates, fluid flow, celestial mechanics. Simulation of dynamical systems. Analog computation.

#### 1196. RESEARCH IN THEORETICAL AND APPLIED MECHANICS

Any term. Credit as arranged. Staff.

Thesis, literature survey, or independent research on a subject of theoretical and applied mechanics. Such research must be under the guidance of a staff member.

#### 1197. SELECTED TOPICS IN THEORETICAL AND APPLIED MECHANICS

Any term. Credit as arranged. Staff.

Special lectures or seminars on subjects of current interest in the Field of Theoretical and Applied Mechanics. Topics and credit hours to be announced when the course is offered.

## WATER RESOURCES

Faculty: David J. Allee, Richard D. Black, Leonard B. Dworsky, Alfred W. Eipper, Louis M. Falkson, Charles D. Gates, Lawrence S. Hamilton, George A. Kiersch, Gilbert Levine, Daniel P. Loucks, Walter R. Lynn, Paul J. Zwerman.

Field Representative: C. D. Gates, 223 Hollister Hall.

### MINOR SUBJECT

#### Water Resources

This Field offers qualified engineers and biological, physical, and social scientists an opportunity to gain breadth of knowledge in water resources planning and management at the same time that they increase their depth of knowledge in their own disciplines. Study in the major subject is complemented by an integrated and interdisciplinary program of study in a minor subject designated as water resources and required of all candidates choosing this Field.

The water resources minor will represent for each candidate that combination of courses, including core courses, seminars, and projects, outside his own discipline, which, in the judgment of his Special Committee, is most likely to meet his needs and interests in the comprehensive aspects of his program.

Complementing major and minor subjects ordinarily will be chosen from the following list (fields and faculty as shown):

Aerial Photographic Studies (Civil Engineering): D. J. Belcher, T. Liang, G. B. Lyon, A. J. McNair.

Aquatic Ecology (Ecology and Evolutionary Biology): J. P. Barlow.

Chemical Engineering (Chemical Engineering): V. H. Edwards, R. K. Finn, H. F. Wiegandt.

Econometrics and Economic Statistics (Economics): T. C. Liu.

- Economic Theory (Economics): L. M. Falkson, J. Vanek.
- Engineering Geology (Geological Sciences): G. A. Kiersch, S. S. Philbrick.
- Environmental Systems Engineering (Civil Engineering): L. M. Falkson, W. R. Lynn, C. S. ReVelle.
- Fishery Science (Conservation): A. W. Eipper, J. L. Forney, D. A. Webster.
- Geohydrology and Hydrogeology (Geological Sciences): G. A. Kiersch, S. S. Philbrick.
- Hydraulics and Hydrology (Civil Engineering): W. H. Brutsaert, J. A. Liggett, G. Terzidis.
- Limnology (Entomology and Limnology): C. O. Berg, D. J. Hall, J. M. Kingsbury.
- Meteorology (Agronomy): B. E. Dethier.
- Natural Resources Conservation (Conservation): L. S. Hamilton.
- Operations Research (Operations Research): W. L. Maxwell, B. W. Saunders, H. M. Taylor.
- Public Administration (Business and Public Administration): E. S. Flash.
- Public Finance and Fiscal Policy (Economics): R. W. Kilpatrick.
- Regional Planning (City and Regional Planning): B. G. Jones, K. C. Parsons, J. W. Reps.
- Resource Economics (Agricultural Economics): D. J. Allee, R. J. Kalter.
- Sanitary Engineering (Civil Engineering): V. C. Behn, L. B. Dworsky, C. D. Gates, A. W. Lawrence, R. C. Lochr, D. P. Loucks.
- Soil and Water Engineering (Agricultural Engineering): R. D. Black, G. Levine.
- Soil Science (Agronomy): M. G. Cline, H. A. Kerr, R. D. Miller, H. F. Mulligan, P. J. Zwerman.

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